Progress in IS

Jorge Marx Gómez
Maria Rosa Lorini *Editors*

Digital Transformation for Sustainability

ICT-supported Environmental Socio-economic Development

Springer

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ICT-supported Environmental Socio-economic Development

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Foreword

The HEdIS project (Hub for Education on ICT for Sustainability) sponsored by German Academic Exchange Service—DAAD, and in which the Carl von Ossietzky University of Oldenburg participated as project coordinator, covers a wide range of different research topics in Sustainability and ICT. These topics are represented in the book "*Digital transformation for sustainability. ICT-supported Environmental Socio-economic Development*" that covers the topics of Innovative ICT for Sustainable Citizenship, Sustainable Entrepreneurship in the frame of ICT, Digital Transformation for Sustainability in Smart Cities, and Data Analytics for Sustainability. The project connects researchers, students, and companies from South Africa (the Nelson Mandela University and the University of Cape Town) with the Carl von Ossietzky University of Oldenburg in Northern Germany. The Carl von Ossietzky University of Oldenburg is proud to have coordinated and supported this impressive project with such remarkable results such as developing new and lasting research collaborations, achieving transfer of knowledge between participating organizations, and contributions to improving research and innovation potential internationally. Facilitation of excellent strategic and applied research resulted in greater impact and high-quality research outputs. It is envisaged that the projects will result in additional future collaborative projects that will improve the quality of research and knowledge levels of all participants. Exchanges of Ph.D. students from the fields of environmental and sustainability studies as well as Computing Sciences have provided the participating scientists and students with the unique opportunity to further develop their research. As part of the 25-year partnership between the Nelson Mandela University and the Carl von Ossietzky University of Oldenburg, we are very proud of the lasting results achieved within this project, e.g., the collaborative research groups and the developed curricula, and look forward to future collaboration with our partner universities from South Africa.

Carl von Ossietzky University of Oldenburg, Oldenburg, Germany

Ralph Bruder
Karsten Speck

Foreword

This book titled "*Digital transformation for sustainability. ICT-supported Environmental Socio-economic Development*" and published by Springer is the culmination of a long-standing and very successful association of 25 years between the Nelson Mandela University (NMU) and Carl von Ossietzky University of Oldenburg (CvUO) as well as a close collaboration between the Department of Computing Sciences at NMU and the Business Informatics department (VLBA) at CvOU for 15 years. The research undertaken for the book falls within the theme of the HEdIS project over the 4 years of the project period and included 21 partners from industry and government and the three universities of NMU, CvOU, and the University of Cape Town (UCT). The main aim of the project was to address some of the pressing global sustainability needs through ICT solutions. These needs include those targeted by the Sustainable Development Goals (SDGs), with a particular focus on those of energy; clean water and sanitation; health; sustainable and smart cities; and education. Some of the ICT solutions include Big Data analytics, Artificial Intelligence, IoT, and data science. The project addressed these goals using a two-pronged approach of both collaborative, quality research and the design and implementing of related curricula for graduate programs in these fields.

Nelson Mandela University, Gqeberha, South Africa

Thandi Mgwebi
Brenda Scholtz
Jean Greyling

Foreword

The University of Cape Town (UCT) welcomes the publication of "*Digital transformation for sustainability. ICT-supported Environmental Socio-economic Development*" which culminates from an exciting four-year Hub for Education on ICT for Sustainability ("HEdIS") project. UCT participated in the HEdIS project with enthusiasm and dedication.

The aim of the HEdIS as well as its approach to bring together practical and research orientated aspects of ICT in order to support the country's sustainability efforts is highly valuable. In particular, the network of university partners and the industry partners participating in the project provided opportunities to build on each other's strengths.

The HEdIS has been developed collaboratively between South African universities, Nelson Mandela University, and UCT, and Carl von Ossietzky University of Oldenburg, in Germany. In the course of the project, the partners shared and networked their contacts with the industry and organizations in their respective countries to broaden the possibilities for their learners' to be given opportunity to improve their competencies in the specific topics. Further, this exposed the students to a global network of academics, researchers, innovators, and industry experts.

UCT strongly shares the premise on which HEdIS has been built in which the collaborative work of the industry and universities in tandem is best suited to push the frontiers of technology, business, and social knowledge. We strive for our institution and our students can be part of this powerful engine for innovation, economic growth, and sustainable development.

For these reasons, UCT is pleased to be part of this growing network where innovative and heterogeneous teaching and learning methods are used to involve and stimulate postgraduate students, giving young researchers the possibility to meet, interact, and eventually produce knowledge. Such knowledge generated through the HEdIS is now published in this compendium.

UCT welcomes this publication which reflects the results of HEdIS project. In addition to the HEdIS outcomes, contributions from beyond the project have been included in the publication to provide opportunities for scholarly engagement between those who were directly involved with the project and a broader spectrum of scholars working in the field.

University of Cape Town, Cape Town, South Africa
Sue Harrison

Introduction

The book focuses on the topics covered during the Summer Schools of the Hub for Education on Information and Communication Technologies for Sustainability Project—HEdIS—in the following sections:

- Innovative IoT for Sustainable Citizenship
- Sustainable Entrepreneurship in the Framework of ICT
- Digital Transformation for Sustainability in Smart Cities
- Data Analytics for Sustainability

Due to the interest in some specific issues, such as agri-tech, and due to the cross-cutting nature of these topics which intersect and blend constantly, the editors added the two following sections to the book:

- ICT at the Service of Sustainable Agriculture
- Cross-Cutting Themes

Participants in all HEdIS Summer Schools, experts, and scholars in these fields submitted their contributions. We received more than 50 manuscripts that went through a blind peer review process. The contributions accepted after a two-round review system are here gathered in a compendium of the use of digital technologies to support economic, institutional, social, and environmental sustainability.

The HEdIS project consisted of a collaboration between three partner universities, namely the Carl von Ossietzky University of Oldenburg in Germany and two universities based in South Africa: the Nelson Mandela University in Gqeberha and the University of Cape Town, in Cape Town. The project was sponsored by the Federal Ministry for Economic Cooperation and Development (BMZ) of Germany and the German Academic Exchange Service (DAAD) which over the years expanded and increased its range of support and collaborations in the region. During the years, many students and professionals could meet and collaborate, particularly during the Summer Schools that took place in South Africa in 2017, 2018, 2019, and 2021. As part of the project, two new curricula were made for Computer Science and

Information Systems departments at partner universities in December 2021. These curricula are meant to help students learn about ICT and sustainability.

The book collects the collaborative compositions stimulated by the activities in the field as well as the encounter with specific realities. For the sake of inclusivity and diversity, the call for contributions was open to external professionals and researchers. As a result, the book consists of 28 chapters; 11 chapters are produced by participants of the HEdIS Summer School over the years, while 17 chapters are contributions from external authors.

This choice allowed the book to include case studies and reflections from a variety of countries; not only Germany and South Africa but also Ghana, Mexico, Tanzania, Macau, and Mauritius. Contributions arrived from Turkey, India, and Mozambique but they do not always fit the scope of this publication. All chapters were subject to a double-blind peer review process prior to acceptance and publication in order to ensure that academic standards were met and that the contributions were relevant.

Book Synopsis

The book presents case studies and analysis of the relationship between sustainability—environmental, social, institutional, and economic—and digital innovation.

The contributions offer a contextualization of the main present and future trends concerning these two elements, with analysis that ranges from the economic, technical, managerial, and social perspectives. The different sections of the book focus on the interactions that they present in existing organizations and aim to highlight the new opportunities, challenges, and threats that may emerge as a result. The contributions arise from case studies and researches carried on mainly in Europe and Africa, with a few contributions from South East Asia and Central America by scientists involved in the fields of Information Systems, Computer Science, Social Development, and Economics.

Themes

The topics of interest in the book are represented by the four themes of the HEdIS Summer Schools. The authors approached them from a technical as well as a societal and political perspective. The themes are inter- and trans-disciplinary and they can overlap. Due to the specific interest in some topics, the sections had been expanded to give space to the issues that impact the countries of origin and residency of many of the contributors, particularly the African and South Asian contexts. Work on socio-economic development, for instance, on the potential impact or value of digital transformations in underserved communities and emerging economies, was encouraged.

1. Innovative ICT Solutions for Sustainable Citizenship

   This theme focused on the business and community value of Information and Communication Technologies. In particular, the chapters highlight the potential contributions of ICT towards environmental, social, and individual contexts. For instance, ICT and water management, climate action and renewable energy, green transport, inclusiveness and security, health and wellbeing.

   ICT systems can be used in manufacturing, transportation, environmental monitoring, hospitals and care facilities, schools and educational institutions, as well as in people's homes and wearable devices to solve problems in the world.

   Contributions can be both conceptual and practical when it comes to ICT-based design solutions that are smart, innovative, and environmentally friendly.

2. Sustainable Entrepreneurship in the Framework of ICT

   The areas of interest in this section cover but are not limited to: the development of a green economy; circular economy with an industrial system that is restorative by design; low impact economy; reduction of global footprint; agri-tech development; ICTs for entrepreneurship; sustainability and socio-economic innovations; environmental entrepreneurial applications and ventures; smart electricity grid solutions; implementation of renewable energies; business models and strategic management for sustainable social entrepreneurship.

   Contributions can be both conceptual and practical when it comes to ICT-based entrepreneurship that is environmentally friendly.

3. Digital Transformation for Sustainability in Smart Cities

   Integrated applications, information processes, network construction, and information generation (sensing and identification) to build Smart Cities should be the focus of this section. Data collection, transmission, process, management, and utilization phases are all relevant for Smart Cities creation and urban planning. Vehicle traffic and parking, environmental pollution and energy production and consumption, surveillance, weather and water systems, smart waste management, smart buildings, etc., can all be addressed from the standpoint of technology, software, and applications (including artificial intelligence), as well as from a societal standpoint (e.g., smart communities and citizens).

4. Data Analytics for Sustainability

   Could data science drive the industrial, societal, and environmental sustainability revolution?

   The big data challenges caused by data growth, timely management, sources, data validation and security are rife with opportunities and risks. Can automation support energy efficiency? Can data centers be optimized to reduce energy consumption and waste? Are our machine learning strategies intended to take into account negative externalities on society and the environment, or only the positive economic outcomes?

   This theme of data-driven sustainability has been approached in the chapters from a critical perspective as well as from a technical and operational point of view.

5. ICT at the Service of Sustainable Agriculture

   A topic that emerged as particularly relevant and that required a separate section from the above-mentioned ones is that of the use of ICT and sustainable agriculture. The contributions received could have been part of other sections, specifically 2 and 4, considering the relevance of data analytics in agri-tech as well as agri-tech in the frame of entrepreneurship. We chose to add a separate section in light of the African and South Asian contexts, where lots of the contributions are from, due to the focus of this book. Those contributions show how agri-tech can make a big difference in the life of people who live in rural areas.

   The chapters are nevertheless not limited in scope and potential practical contributions to growers, food processors, distributors, retailers, consumers, and waste managers in areas where food security is at risk. The solutions suggested can, in fact, play a role in ensuring an integrated, sustainable agricultural system globally.

6. Cross-Cutting Themes

   While all topics related to sustainability and technology generally require a holistic approach and integrate aspects from various domains (political, social, economic, environmental), we found the need to dedicate a section to papers that specifically do not focus on one single domain but showcase a socio-technical approach. Particularly, when suggesting viewpoints and designing solutions, the authors tried to balance environmental, social, and economic considerations. Sustainable industrialization, social protection, and inclusive education are among the focuses of these chapters.

Acknowledgements

The editors would like to express their gratitude and appreciation to all the professionals involved in the development of the project and particularly in the finalization of this book.

All of the contributions submitted were carefully reviewed, and while not all of them were accepted for publication in this compendium, we appreciated the time and effort that many researchers put into the submission. We hope that the feedback from the reviewers can offer suggestions and directions to all the authors to improve their work, for this as well as for further publications.

We take this occasion to thank the huge number of reviewers from around the world who made it possible to conduct a double peer review. Due to the blind system adopted, we can only list their names in alphabetical order and once again acknowledge their fundamental contribution to this publication:

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Many contributions represent collaborations between postgraduate students and young researchers with established academics; other contributions are the product of the encounter of the participants in the HEdIS project in a cross-cultural environment where they had the opportunity to work with researchers and practitioners from around the world.

The businesses and organizations that took part in the activities not only gave their time to show off their skills, but they also stayed available for more collaborations on theory development and the analysis of the praxis.

The industries and organizations involved were:

- Artombo, South Africa
- BKB Ltd., South Africa
- CloudStrength, South Africa
- Council for Scientific and Industrial Research, South Africa

- East London IDZ, South Africa
- East London Municipality, South Africa
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- Rhino Group, South Africa
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- SAREBI, South Africa
- SARETEC, South Africa
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- Sustainable Seas Trust, South Africa
- SYSPRO, South Africa
- The Abat, Germany
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- The Hope Factory, South Africa
- The Peak Lab, Oldenburg, Germany
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- uYilo, South Africa
- Volkswagen Group, South Africa
- We Can Do Projects, Germany

Last, but not least, our thanks to the funding agencies of the HEdIS project. This book is part of the project that allowed many students, graduates, and researchers to meet, learn, and collaborate. This compendium is a proof of the results achieved.

Further information is available on the following website: https://hedis-project.org/

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Part IV Data Analytics for Sustainability

Part I
Innovative ICT Solutions for Sustainable Citizenship

Addressing Sustainability Challenges of the South African Wine Industry Through Blockchain-Related Traceability

Robyn Blake-Rath, Anne Christin Dyck, Gerrit Schumann, and Nils Wenninghoff

Abstract The wine industry represents an important economic sector for South Africa, increasingly facing challenges through fraudsters, misdeclaring products by specifying false geographical regions or ingredients. Ensuring robust traceability therefore plays a major role in all three sustainability pillars. Current measures, such as certificates, neither guarantee transparency nor protect against counterfeiting. Therefore, the concept of supply chain traceability has emerged. In the South African wine industry this aims at ensuring the transparent and complete tracking of wine, including all ingredients and modifications. In order to additionally encounter false digital information, blockchain technologies are a major opportunity, as they offer the possibility of transmitting tamper-proof information, using a decentralized database shared by many participants. So far, the discussion of the potentials that this technology offers to wine traceability lacks the connection to the context of sustainable development. Therefore, this paper provides an overview of the opportunities applicable by different blockchain methods to enhance and guarantee traceability within the supply chain, simultaneously addressing sustainability challenges. Furthermore, an example of a possible business model opportunity is presented. By implementing this approach, consumers can not only be prevented from buying counterfeit products but also be enabled to make decisions based on economic, environmental, and social factors.

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Keywords Traceability · Sustainability · Wine industry · Blockchain · Product transparency

1 Introduction

The South African wine industry represents an important economic factor for the country, which has significantly expanded in value over the past decades. Specifically, the export performance of the South African wine industry has increased by 153% between the years 2005 and 2019. This represents an annual growth rate of 10% (Lubinga et al., 2021). In terms of global wine production, South Africa produces 3.3% of the world's wine and ranks eighth in total wine volume production (Wines of South Africa, 2019). The high demand for South African wine is motivated to a great extent due to its high quality, placing it in the premium brand segment (Crous & Agabu Phiri, 2017). This offers great potential for high profits, so that counterfeit wine has become a global multi-billion-dollar industry, through fraudsters misdeclaring the product by specifying a false geographical region or false ingredients, for example, and thus charging a higher falsified price.

In order to protect the geographical wine origins, the South African wine industry applies different acts such as the Merchandise Marks Act 17 of 1941, the Liquor Products Act 60 of 1989, the Trade Marks Act 194 of 1993 and, in part, the legislation for the protection of traditional knowledge (Lubinga et al., 2021). The concrete challenge, however, is not the lack of certificates, but the actual implementation of traceability. In order to reduce harmful impacts in food supply chains, the concept of traceability has therefore grown into a significant issue and has become a priority for all food chain actors, including both producers and consumers (El Sheikha, 2020). Traceability can be broadly referred to as the ability to track and trace information in the global food system (Djelantik & Bush, 2020). This can include the set of data and operations from the production and utilization chain to generate the required information about a product (Olsen & Borit, 2018). "Traceability system" is therefore a generic term describing principles, practices as well as standards used to achieve product traceability (Olsen & Borit, 2018).

The advantages of a robust traceability system are manifold and have the ability to not only decrease fraud, but more importantly address sustainability challenges in all three pillars (environmental, social, and economical) throughout the industry. Economical: Traceability optimizes business processes along the supply chain, which can lead to improved efficiency, reduced lead times and as a result to cost reduction (Scholten et al., 2016). Social: Traceability systems help to improve transparency throughout supply chains, providing reliability and access to information for all involved actors as well as consumers. Environmental: Transparency enables proof of supplier compliance with standards and regulations and verifies geographic origins. Together this strengthens the reliability of cooperating suppliers, governments, certification companies, and other market actors, as well as substantiating statements about product-specific information, manufacturing, and working conditions (Venkatesh et al., 2020).

Most of the research surrounding traceability focuses on the fields of blockchain and technology or analyzes the correlation between sustainability and traceability. To the best of our knowledge, no papers have been published to date on blockchain-based wine traceability in the context of sustainable development. Therefore, this paper provides an overview of the opportunities that can be applied by blockchain methods in order to enhance traceability within the South African wine industry and address sustainability challenges.

Firstly, an introduction into the topic of traceability of wine in South Africa is provided in Sect. 2, which covers the current situation of wine certification. The third section discusses traceability as a tool to ensure reliability of sustainability claims, while Sect. 4 discusses the opportunities resulting from blockchain-based traceability. In addition, a possible business opportunity is presented in Sect. 5, followed by a summarizing conclusion and outlook in Sect. 6.

2 Traceability of Wine in South Africa

Introduced in the 1990s, product traceability is still being studied by scientific and industrial bodies (Bevilacqua et al., 2009). As part of these studies, different systems have been developed specifically for wine traceability (Cimino & Marcelloni, 2012; Biswas et al., 2017). In the corresponding wine supply chains, the claim is to ensure traceability from grape production through processing up to wine distribution (Ahamad et al., 2018). Figure 1 shows the essential information that should be traced within a wine supply chain.

To make this information traceable from the grape producer to the consumer, the respective supply chain actors must assign and record appropriate identifiers for the traceable entities that they manage and create a record for each of these identifiers, containing all the necessary information corresponding to specific entities. In addition, each actor must create the links between identifiers, which determine correlated entities. The filler/packer can link the lot number of the bottles, for example, to the lot number that identifies the bulk wine used to fill the bottles (Cimino & Marcelloni, 2012). Traceability can encompass different stages of the supply chain and range in scope and differentiation. Despite all research and development that has already been conducted on wine traceability, such extensive systems are mostly implemented by

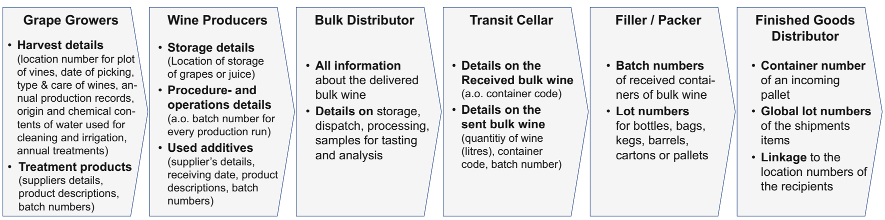

Fig. 1 Traceable information within a wine supply chain (following Cimino & Marcelloni, 2012)

large companies, which are characterized by a closely aligned supply chain and a considerable use of information and communication technology (Gandino et al., 2009). Smaller companies either do not implement these systems at all, or they add a traceability management to their normal business operations, often resulting in reduced efficiency and increased costs (Cimino & Marcelloni, 2012).

Regardless of the technical requirements and consumer needs, a traceability system must also comply with legislation. Laws, international agreements and standards lay out the basis for required traceability systems for food origin, hygiene, and safety in many countries worldwide. For example, the obligation for traceability in the European Commission General Food Law Regulation 178/2002 lays down the general principles and requirements of all agri-food products, including wine. The law makes it obligatory for the industry to implement a certain level of origin and safety traceability systems (European Union, 2021). To expand corporate due diligence, the European Parliament formulates requirements for a new EU law that holds companies liable whenever they violate or contribute to violations of human rights, environmental standards, and good governance. The rules on due diligence for supply chains should also guarantee access to legal remedies for injured parties. The EU Commission has announced a corresponding legislative proposal for spring 2021 (European Parliament, 2021).

In recent years, there has been a trend toward stricter food safety and traceability standards, especially in major importing countries and sectors. In South Africa food traceability systems have been mandatory since 2018. Products are expected to adhere to the R638 "*Regulations Governing General Hygiene Requirements for Food Premises, the Transport of Food and Related Matters*" of the Republic of South Africa. This regulation essentially relates to food safety, but also defines which aspects of production must be taken into consideration. Producers in the food industry must have the necessary resources, production as well as working conditions and infrastructures in order to guarantee the requirements (DoH, 2015). The main challenge in this regard is that producers lack the relevant knowledge that is necessary for a proper implementation of the regulation (Teffo & Tabit, 2020).

3 Traceability as a Tool to Ensure Reliability of Sustainability Chains

Traceability is considered to be a vital issue for all participants in the food supply chain (Scholten et al., 2016). Determining the reliability of certain claims associated with a product's properties can strengthen transparency along the supply chain. This is particularly essential for companies in order to achieve their sustainability goals. Global supply chains with overseas buyers, which also affects the South African wine industry, are becoming increasingly complex. Although the wine industry has traditionally been classified as fairly sustainable, plagiarism scandals and falsely declared wine qualities have increased distrust, demanding for security for consumers (Giacomarra et al., 2016). This includes the counterfeiting of thousands of bottles of "Brunello di Montalcino" and "Chianti," falsely labeled with geographical indications, or frauds involving luxury segment brands such as "Moët & Chandon" (Stranieri et al., 2018). Consequently, initiatives and requirements that ensure sustainability of practices of the entire winemaking process and the quality of the product have become of utmost importance to consumers and obligatory for protecting human health (Giacomarra et al., 2016).

The potential benefits of the wine industry to track their products from consumption across the supply chain are manifold and can be assigned to the three sustainability pillars: environmental protection, social equity, and economic development (Venkatesh et al., 2020). As consumers are beginning to pay more attention to the first two pillars at the expense of the economic dimension, environmental and social sustainability are the two major concerns in global supply chains, with regard to sustainability aspects (Ten Have & Gordjin, 2020). The United Nations Global Compact's guide for traceability states that traceability systems ensure "*the reliability of sustainability claims*" (United Nations Global Compact, 2014: 6). This is reflected in the recent discussion on supply chains sustainability, where traceability is seen as an enabling tool for improved sustainability performance (El Sheikha, 2020).

The expansion of traceability is beneficial to the wine industry, creating both transparency and security to consumers. Modern society increasingly expects sellers to disclose information on social sustainability. Supply chain related social sustainability is mainly related to exploitation protection, anti-corruption, as well as providing a healthy and safe environment including fair wages (Venkatesh et al., 2020). Traceability can also help to ensure the quality of raw materials, introduced into the food chain, allowing certification, accreditation of their products and constitutes protection against plagiarism (Venkatesh et al., 2020). This increased transparency can quickly locate problematic items. This allows traceability systems to be used as a control system, preventing fraud, unfair competition and leads to sustainability in trade, even reducing image damage when incidents occur (El Sheikha, 2020). Furthermore, a shortening and disentanglement of international value chains in the agricultural sector helps strengthen intraregional trade and increases the system's resilience.

Through traceability social sustainability of companies becomes visible, ensured, and strengthened by these measures and standards. These are mainly controlled by consumer demand (Giacomarra et al., 2016). Companies can reassure this demand by participating in voluntary standards to positively influence their ethical reputation and simultaneously helping small farmers integrate into global food markets. In addition, these standards can also represent a strategic competitive market advantage (Giacomarra et al., 2016). Voluntary traceability standards do not replace mandatory traceability, but they are usually implemented by the wine-making industry as an instrument to provide the quality standards security and to coordinate vertical relations through improved transaction transparency, in comparison to legally required traceability (Moscovici & Reed, 2018).

Compared to other food products from the agricultural sector, where businesses use voluntary standards and certification primarily to strengthen their position in the export market, producers in the wine-making industry use these standards for organizational efficiency and ethical reasons. Giacomarra et al. (2016) show that the implementation of voluntary sustainability standards, which require high transparency and therefore a robust traceability system, can improve business performance. Wineries adapting to these standards show better economic performance than non-certified wine companies (Giacomarra et al., 2016). This highlights the need for wineries to implement efficient traceability systems capable of controlling quality risks and liabilities within the supply chain (Stranieri et al., 2018). Efficient and effective end-to-end traceability systems are often challenging and expensive to implement, especially in developing countries. The key driver of developing and implementing traceability systems is the private sector and businesses in particular, which act on the export market, such as the wine sector, to remove barriers and use their market power to set new standards.

4 Blockchain as a Supply Chain Solution

The blockchain is a decentralized, distributed system based on chained blocks and was initially developed by Haber and Stornetta (1991). Building on this, Nakamoto (2008) established a distributed database system for the digital currency Bitcoin (Nakamoto, 2008). In this case, the blockchain is stored on a large number of decentralized ledgers, verifying new blocks and storing them in the blockchain. There must be a consensus among the majority of nodes during this process. The blockchain is tamper-proof as long as the majority of its attendees is interested in the integrity and correctness of the blockchain. Since all transactions or entries are stored in the blockchain and cannot be deleted, it offers additional use cases besides financial systems (Tasatanattakool & Techapanupreeda, 2018; Dimitrov, 2019; Antonucci et al., 2019). Blockchain technologies, for example, offer new approaches and opportunities for supply chain traceability. Due to globalization and the increasing number of producers involved, digital and location-independent solutions are necessary.

The blockchain can be operated in three different varieties: permissionless (Bitcoin, Ethereum), permissioned, and private. Permissionless bears the risk of a 51% attack, so that the integrity of the blockchain cannot be guaranteed. In the context of the supply chain, such an attack would be conceivable, as the participation of external miners would be unlikely due to a lack of compensation. Criminal actors could use a 51% attack to infiltrate counterfeit blocks and, as a result, place forged products into circulation. Permissioned systems involve existing miners/participants confirming new attendees. The advantage lies in the simple extension, nevertheless a security risk in this type of blockchain is apparent. This is also the case for the encryption of sensitive data, as it is associated with greater effort. A private blockchain contradicts the decentralized approach of multiple participants, since the access is centrally determined for a limited set of participants. While this provides the security of not adding criminal actors as participants to the blockchain, external ones must trust the attendees involved, as they could theoretically modify the blockchain (Dujak & Sajter, 2019). Both private and permissioned forms would be conceivable approaches in wine supply chains. A permissionless approach would have to enable the acquired participant number to ensure integrity.

The blockchain as a technology in itself, offers two specific characteristics, which bring a particularly large benefit to the supply chain. On the one hand, information is secure, verifiable, trustable, easily accessible, as well as the fact that exchange happens in real time. On the other hand, so-called smart contracts can be used. They provide an automatic transaction verification and condition-based execution of a given transaction (Dujak & Sajter, 2019). These properties can be used in different ways. Dujak and Sajter (2019) have defined seven possible application areas: the traceability of a product origin, the visibility of product flows throughout the entire value chain, demand forecasting due to precise data collection, open access to information, decreasability of fraud and counterfeit as a result of the traceability and visibility, transaction automatization, and finally the reduction of negative impacts on the environment (Chapter "MoPo sane: Mobility Portal for Health Care Centers"; Dujak & Sajter, 2019). The concept of blockchain as a supply chain tool for tracing wine, for example, has already been explored by Biswas et al. (2017) focusing on Australia as a case study. The developed system should ensure traceability and consequently offer higher transparency, resulting in a reduction of fraud and product counterfeiting. Furthermore, the illegal use of pesticides should be detectable (Biswas et al., 2017).

The presented system is based on a private blockchain, a previously distributed key is used for encryption and decryption of sensitive content, thus distinguishing public and non-public data. The supply chain entities include grape growers, wine producers, bulk distributors, transit cellars, fillers/packers, finished goods distributors, wholesalers, retailers, including other entities such as suppliers for production goods or transport companies. Every bottle of wine has a unique ID. The consumer can check this ID and acquire access to all blocks related to this bottle. This system provides supply chain transparency throughout the entire chain from the grape grower up to the retail store. Every ID is unique and part of the supply chain. External entities are unable to add falsified IDs due to the private nature of the supply chain (Biswas et al., 2017). Copying the ID is also not practical, as retailers are part of the blockchain, and the sale can be implemented as the final block so that the purchased bottle can actually be verified via the matching ID.

5 Business Opportunity

The need for a sustainable, secure, and transparent tracking technology is therefore apparent. Blockchain has the ability to close this void. A challenge for the operation is to ensure the security of the blockchain, simultaneously ensuring the trust for the end consumer. As a result, we therefore propose an independent service provider that operates the blockchain of both producers and retailers. Startups have already been able to prove that blockchain is an effective market solution for the supply chain connection. “Openport,” for example, offers a solution for transportation, connecting producers with transport companies (Lim & Noman, 2018). “OriginTrail” offers a blockchain-based data exchange platform, enabling different supply chain connections (Rakic et al., 2017). Additionally, Xevgenis et al. (2020) also show that other startups implement blockchains in supply chain management for other use cases.

In the following, based on parts of the sustainable business canvas model by Joyce and Paquin (2016), a possible entrepreneurial opportunity including blockchain-related traceability in the wine supply chain will be presented. A transparent, secure, and reliable supply chain embedded in a blockchain depicts the *value proposition* of the business model. *Key activities* are represented by the operation and development of the blockchain itself. Furthermore, product marketing, such as tracking, has to be undertaken. In addition, an interface for producers, traders, transport companies, as well as a frontend-interface for end customers has to be developed and operated. The producer’s contact channels, together with the blockchain portray the *key resources*. The latter can either be developed in-house or built on existing blockchain technology. The *contact channels* to potential customers can be built through digital interfaces, an app and a website. Stakeholders within the wine industry, including sales and end consumers can be defined as potential *customers*. However, producers can be seen as the prime target group, followed by transport companies and finally trading partners. Transport companies and blockchain developers are possible *partners*. *Costs* include marketing, software development, as well as the operation of the required server hardware. The main *source of income* can be generated by providing storage capacity within the blockchain, by the usage of micro transactions. These small fees are charged for every stored information as well as for all individual intermediate steps. Another source of revenue can be determined in the sale of pseudonymized data.

The *functional value* is the key component of economic business models. In the presented business opportunity, the functional value would be represented by the decentralized and connected storage of the complete supply chain, not only focusing on partial supply chains. This enables an overview of possible ecological optimization potentials and in addition creates transparency for the end customer within the transport route. Development and operation are more appropriate in production. Here the blockchain represents the major ecological factor. Blockchain processes without proof of work, for example, are suitable for reducing the required computing power and the amount of energy required. The number of nodes can additionally be reduced by a private blockchain. As a result, this would, in turn, reduce the amount of energy and required materials, such as servers. The existing computer hardware can continue to be used after the end-of-life period, avoiding additional emissions. An important factor to be considered are the supplies and out-sourcing. Computing power could be booked on demand in the cloud. In the case of using personal computer hardware, it has to be taken into account that electricity is consumed. The environmental impact relies almost entirely on the production method used for the electricity required, as well as on the computer hardware. If the electricity is generated from renewable energy sources, the impact on the computer hardware itself can be reduced. The environmental benefit therefore lies predominantly on the following aspects: reduction of paper usage, multiple data storage, associated additional electricity costs, generated knowledge, and the resulting optimization potentials. In addition, the transparency offers the end consumer the possibility to make the purchase decision dependent on ecological factors instead of the sole consideration of economic factors.

The major *social value*, evaluated from the perspective of the *employees* working within the supply chain, is the protection from exploitation and corruption. Furthermore, they are provided a healthy and safe working environment, together with fair wages. From the *end users'* point of view, the *social value* lies in the fact that they can be assured of transparency, safety, as well as a high and stable quality of food. In terms of organizational structure and decision-making policy, different variants are conceivable to define the *governance* of the company. Investors could be involved in certain decision-making processes, which would then strengthen transparency and social trust. The development of *local communities* of suppliers is therefore enhanced and long-term existing, due to the newly gained security and transparency within the supply chain. By reducing the risk of exploitation, higher returns can be generated, reinvested and thereby product quality increased as a result. A successful and widespread establishment of the business concept in the wine supply chain could additionally have a strong impact on other domains, where traceability weaknesses are still present. This, in turn, could be characterized by a transformation of the *social culture*. In contrast, a negative *social impact* could alternatively be seen in large corporations only accepting supply chain partners who participate structurally, organizationally, and monetarily in the blockchain system. Participants in classical supply chains who cannot or do not want to participate for various reasons in the blockchain concept, could have long-term competitive disadvantages as a result.

6 Summary and Conclusion

The wine industry represents an important economic sector for South Africa. Ensuring robust traceability plays a major role in addressing challenges in all sustainability pillars (environmental, social, and economical) and with this securing the originality of the South African wine. To guarantee this, various certificates were introduced at an early stage, nevertheless, they can neither guarantee transparency nor protect against counterfeiting in today's world. For this reason, the concept of supply chain traceability has emerged. The advantages of a robust traceability system are manifold. Traceability optimizes business processes along the supply chain, which can lead to improved efficiency, reduced lead times and, as a result, to cost reduction. In the context of the wine industry, it is intended to ensure the transparent and complete tracking of the wine, including all ingredients and modifications. In addition to the associated challenge of linking and sharing the relevant information throughout the entire supply chain, digital information is, however, also at risk of being falsified. As a result, blockchain technologies can be seen as a major opportunity, offering the possibility of transmitting information in a tamper-proof manner using a decentralized database shared by many participants. The applicability and potential of blockchain technology within food supply chains has already been explored in several studies. Although blockchain has now evolved into a mature technology, it is rarely considered in traditional business models. Moreover, the discussion of the potentials that this technology offers, to wine traceability in the context of sustainable development, is insufficiently investigated. Therefore, this paper provides an overview of the opportunities that can be applied by different blockchain methods in order to enhance and guarantee traceability within the South African wine industry and simultaneously address sustainability challenges. Following the Triple Layered Business Model Canvas, a concrete example of a possible business model opportunity is presented. By extending wine traceability approaches with ICT opportunities addressing current sustainability challenges within supply chains, consumers can be enabled to make decisions based on economic, environmental, and social factors. The limitations lay predominantly in the willingness of the parties to participate. The benefits, however, surpass this by far by preventing counterfeit, ensuring safe working conditions, and providing product transparency by tracing origins, as well as social and ecological information.

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Information Technology Infrastructure Sharing Effects on the Environment and the Delivery of Equitable Public Services in Zimbabwe

Guidance Mthwazi

Abstract Upon rapid utilization of Information and Communication Technology (ICT) services, Information Technology Infrastructure (ITI) sharing has become one of the most topical concerns for several developing economies in Africa. Emerging Internet Service Providers (ISPs) in Zimbabwe face the dilemma of either investing in their own ITI or sharing infrastructure major telecommunications firms have already established. This study delved into the effects of ITI sharing on ISPs. It detailed how ITI sharing is affecting the emerging ISPs more than established ones, a development that cascades to compromised sustainability of the environment and equitable service provision to the citizens of Zimbabwe. Findings indicated that because of the monopoly and regulations exerted by established firms and government, respectively, emerging ISPs in Zimbabwe face numerous hurdles in the provision of Internet services hence resort to means that are detrimental to environmental sustainability and non-equitable in the provision of this public service. By review of approaches taken in other countries, the inquiry employed the Zimbabwean case to address this issue. Detailed enquiries on already established firms, new players, and stakeholders were conducted through in-depth one-on-one interviews. The study was qualitative in nature, making use of key informant interviews, document analyses of government policy, local authority regulations, and related research publications.

Keywords ITI sharing · ISPs · Environmental sustainability · Equitable public services · Policy

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1 Introduction

Information Technology Infrastructure (ITI) sharing is the utilization of existing and future infrastructure by two or more telecommunications license holders subject to an agreement specifying relevant commercial and technical terms and conditions (POTRAZ, 2016). Similar definitions emerge from other scholars (Frisanco et al., 2008; García-García & Kelly, 2015; Hanafizadeh et al., 2019; Zheng et al., 2017) who emphasize commercial/business terms as the most crucial for most firms. It has been indicated that ITI sharing is mostly characterized by these business terms (economic) followed by geographic models and the technical models (Frisanco et al., 2008). While terms of sharing deals differ firm to firm, what is important to note is that lack of adequate sharing frameworks has put some firms at a disadvantage (emerging ones in this case). These sharing terms are agreed to by the infrastructure provider and the infrastructure seeker (provider and seeker, respectively). For close to two decades now in Zimbabwe, this has been inadequately regulated in terms of government policy and this has seen inequitable agreements between concerned parties. As a result, there have been rising complaints between seekers and providers of ITI to an extent that the government had to amend policy to resolve these issues.

The Telecommunications Board of the Government of Zimbabwe (GoZ), the Postal and Telecommunications Regulatory Authority of Zimbabwe (POTRAZ), let private owned companies to have dominance in the establishment of ITI prior to enacting appropriate sharing, use, and management regulatory measures. GoZ has lately enacted some measures, i.e., SI 137 of 2016. It is, however, debatable if the government initially failed to regulate private entrepreneurs developing ITI, was incapacitated, lacked skilled personnel, had no strategic framework, or turned a blind eye. This study, conducted in Zimbabwe was motivated by the interactions between established ISPs who are well equipped, infrastructure wise and the emerging ones. GoZ proposed to regularize ways in which commercialization of this ITI is handled by imposing a Statutory Instrument (SI) in November 2016. All these concerns seemingly reflect on economic, geographical, and technical perspectives, but they cascade to other crucial issues. While this study assessed the effects of ITI sharing deals between major and emerging firms, the inquiry narrowed down to the environmental sustainability concern and the equitability this has on the delivery of public services to citizens, a gap that was shown to be highly important.

1.1 Statement of the Problem

It is vital for every nation to demarcate between services that the government should provide to its citizens as a mandate and those that are not. Since the Internet boom, a little over two decades ago (Hendershott, 2004; Owusu-Agyei et al., 2020; Oyelaran-Oyeyinka & Lal, 2005), with less than 1% connections in Sub-Saharan Africa in the year 2000 (Edo et al., 2019), Internet use and the Internet service provision business gained marketability at an exponential rate. The ITI backbone, sharing, and governance, upon which Internet services depend have lately taken center stage and are shifting the global geopolitical economy (DeNardis, 2012; DeNardis & Musiani, 2016; Winseck, 2017). Most African countries then during the late 90s boom, could have assumed this service as a privilege or were not yet knowledgeable enough to perceive how mandatory it will become. As such, the problem currently is that emerging ISPs are in a dilemma trying to establish their own infrastructures with little success and having to contract established Internet Access Provider (IAP) services for ITI lease agreements (Main, 2001; Mbarika, 2002; McNally et al., 2018; Schumann & Kende, 2013). Major concerns emanated from established firms supposedly charging high rates, denying emerging ISPs let outs, or offering unreasonable lease agreements.

On the other hand, government requirements became too cumbersome for emerging ISPs to establish their own infrastructure. For those that managed to get licensed, the road excavations were not properly rehabilitated, a development that motivated the study to investigate not only the issue of accountability toward sustainable citizenship through offer of equitable public services but also socioeconomic and environmental sustainability implications. Above the rising costs of ITI establishment, emerging ISPs had to deal with local authorities separately from national regulations, especially the town planning units to get licenses and maps for land excavations. In most cases, they were denied permission because of lack of proper equipment to rehabilitate road works after excavation.

In other cases, where these emerging ISPs desire to establish ITI because of the market share density advantage, they were prohibited to do so because there is already adequate coverage in terms of Internet connectivity. To some extent they have been offered highly remote sites instead of the sites they desire. What the GoZ did by introducing the SI 137 of 2016 is one way to solve this problem, but it is not the least enough considering the issues already emanating from the Instrument that has not been fully implemented yet. Stemming from that are several other issues of concern but this inquiry focused on the implications of ITI sharing and the advent of the SI 137 of 2016 on environmental sustainability and equitable public service provision. In addition, apart from the equitability of public service provision, the environmental sustainability issue loops backs to the citizens, as human life is dependent on the natural environment (Melville, 2010).

1.2 Research Question

Table 1 outlined the aim of the study, which is reflected in the main objective. It also broke down the main objective into smaller achievable objectives that were pivotal in answering the research question.

Table 1 Research questions and objectives

Main question	Main objective
How can ITI sharing approaches promote environmental sustainability and equitability of public service delivery?	To examine ITI sharing approaches that promote environmental sustainability and equitability of public service delivery.
Supporting/sub-questions	Supporting/sub-objectives
How do the current sharing deals affect environmental sustainability?	To examine the effects of the current sharing deals on environmental sustainability.
How do the current sharing deals affect equitability of public service delivery to citizens?	To assess the effects of the current sharing deals on equitability of public service delivery to citizens.
How can the government better intervene in ITI sharing?	To identify improved government intervention measures in ITI sharing.

2 Literature Review

2.1 Introduction

Zimbabwe is counted among developing countries in the globe (United Nations, 2020). The state of its Information and Communication Technologies (ICTs) in comparison to those of developed countries further asserts this claim. It has been established that if the government is not dominating in terms of ITI coverage, it should at least regulate how it is utilized and managed (Lee et al., 2008). Even as the infrastructure is being developed, the government should be able to know and regulate its usage, structure, and costs of the information highway. It should be able to determine what contents will eventually be delivered over the technological pathways, in what forms, by whom, for what purposes, and at whose expense (Schaefer, 1995). Once infrastructures become too private and custom then Internet access at acceptable service quality, affordability, and speed is compromised. Instead of usage rates going down it is most likely that only those who afford will receive high quality service, a development undesirable to most if not all governments.

Schaefer further ascertains that the rush to privatize the information highway in this case done through monopoly of infrastructure development by private companies has long-term effects even on the democracy of a nation. The more private the ITI is, the more it undermines the system’s long-range potential to enhance democratic participation through public dialogue and decision-making. There ceases to be transparency and there is a lack of trust by the public consumer to trust the medium in exchange of private and confidential material. Users in southern African nations experience breach of privacy and confidentiality by their governments which protect their interests at whatever costs. There is no concrete enforcement on policies that empower the citizens to challenge their governments using the existing justice systems.

In Zimbabwe, all information is accessible to the government, and in a case where the government desires to charge a citizen with any form of cybercrime, it accesses all communication at any level of privacy. In what citizens deemed as a threat to their social media privacy, the government through the Ministry of Information, Publicity and Broadcasting Services warned users of social media through a state-owned newspaper, The Chronicle, not to circulate material that can incriminate them on social media (The Chronicle, 2019). This development had been going on in several other countries, where governments access private citizen-to-citizen communication if it is “a threat to national security” (Aistrope, 2016). Consequently, that saw the subsequent upgrade of social media platform like WhatsApp secure their information highway by end-to-end encryption even for group chats.

While ICTs enhance meaningful learning (Makrakis & Kostoulas-Makrakis, 2020) and ways of knowing more about the world (Thompson & Walsham, 2010; Walsham & Barrett, 2005), they are only an immediate advantage to those connected. Their utilization shapes social relationships, values, and hegemonic outcomes of the users (Schaefer, 1995). Therefore, technological development became one of the major driving forces shaping society, a theory also ascertained by Giddens’ Structuration Theory that institutions and humans cannot be separated, i.e. what humans are socially is a direct result of the structures and organizations they create through interaction and the structures or institutions available are a result of how humans behave (Giddens, 1984; Jones & Karsten, 2008). A nation in its regulation of ITI, i.e., its information highway media, must be able to observe constitutional obligations through how it values the importance to honor user wishes ahead of its control of this ITI. It must quickly sieve between user private matters and issues of national security without violating consumer rights. The more control and management responsibility a nation assumes over its ITI and its sharing policies the more developed it is considered.

2.2 *The Concept of ITI Sharing*

ITI sharing was not a popular concept for a few organizations in the ICTs domain, for most it was just a huge yawn (Best & May, 1997). At the time ISPs did not understand how great a role it would play in the information age. It has however become a cash cow for established IAPs in developing countries and a constraint to emerging ISPs. Best and May (1997) best defined ITI as resources shared across multiple initiatives where the cost cannot be justified by a single project and the attributes can be subject to strict standards. According to this statement it is inevitable that it must be managed. All resources shared must be managed to avoid conflict and exploitation of disenfranchised parties.

Since ITI is a shared resource or is at least becoming an immensely shared resource, regulation policies have become complex. Apart from the emerging challenges to policy formulation, ITI sharing has become a promising concept for African countries dealing with digital divide issues (Arakpogun et al., 2020), as it accelerates connectivity (Strusani & Houngbonon, 2020). However, management techniques and policies have played a big role as it was shown that it is where problems emanate from. Challenges from as basic as, to whom does ownership of

Table 2 The six steps of Infrastructure Management

1. Centralize management responsibility	This method would not be popular with your team as the Chief Information Officer but has proven to be the best because all experts on different challenges are gathered centrally.
2. Define architecture and establish standards	Once standards have been set make sure everyone complies despite their level of knowledge or expertise. One advantage of standards is equitability.
3. Perform gap analysis	This is the only way to follow-up on milestones because it communicates where the firms are and helps establish where they want to go.
4. Secure the funding	At the end of the financial resource analysis infrastructure ceases to be a technical issue and becomes a monetary issue. Usually, the abundance of financial resources determines the better the infrastructure. Investments should be wise; control, budget, and save.
5. Execute upgrade program	Infrastructure developers shall go into ITI establishment with a clear-cut schedule determining when and which sites will be a priority when it comes to upgrades. Starting with huge sites and ending with smaller sites proved to be more cost effective.
6. Anticipate needs in advance	By participating in business leadership meetings, and user needs, firms stay abreast of the capacity requirements, trends, and usage spikes, hence avoid unwanted surprises.

Source: Best and May (1997)

this infrastructure lie with, to complex challenges like how firms share maintenance responsibilities, how quickly down times are attended to instantaneously arise. As such, there has been no reference in literature to examine ITI sharing management issues from an African perspective. Table 2 shows a summarized six-step outline on how to better manage ITI in the case of sharing deals between providers and seekers. Adopted and customized, this might be a start to formulating context-specific ITI management strategies.

It has been established that ITI sharing is a global challenge, but the levels of disputes differ from nation to nation depending on how and when they began to work toward its management. In the USA, Public Information Infrastructure (PII) development was established over and above the imminent universal and public monopoly networks. This concept is like their National Information Infrastructure of the mid-90s but in this case the focus is local, and the services are more advanced. Instead of the usual access level, the focus was to channel resources to develop state-of-the-art technologies in selected local areas. PIIs helped streamline internal operations of municipal government, improve delivery of town services to citizens and businesses, reduce traffic congestion and air pollution, bring new educational opportunities to local schools, and help local businesses prosper in a global marketplace. This development addressed equitable access to the Internet for ordinary citizens but most importantly environmental sustainability goals. PIIs built electronic cities to link homes, schools, libraries, hospitals, and small businesses to this ever-growing information superhighway (Shin et al., 2006).

The major problem faced in this development was that there were significant operational gaps between different players in the development consortia. Other players in the consortia were government, equipment provider groups, service provider groups, user groups, and network groups. This made it difficult to develop quickly because of push and pull factors among these groups emanating from their different needs and development ideas. The other challenge was that the development of these networks left general users out of the design process, an issue that usually breeds user disgruntlement. The last issue was that the developmental processes were infrastructure oriented, so this meant that matters of compatibility with other technologies were soon going to be a daily challenge upon implementation. Clearly, the challenges of this seemingly great initiative were shown to be mostly technical but still put the needs of the public and sustainability of the environment ahead.

Many governments were immovable and skeptical on hiring expertise from other nations for the fear that they may create secret trap doors during their work to use later to infiltrate government protected information. This has impeded the development of ITI especially in countries where there is scarcity of experts. However, organizations have embraced that, infrastructures keep on evolving with the introduction of new technologies now and then (Sharma & Gupta, 2002). Today's security measures might become weak for tomorrow's threats; therefore, organizations need to invest immensely in their own human resources to minimize the cost of calling in foreign experts repeatedly. In addition, it proved easier and much more manageable for a company to sign a non-disclosure contract with an expert who is also a national of that country compared to a foreign expert as policies and law will differ nation by nation.

2.3 The Concept of ITI Sharing in Zimbabwe

The Zimbabwean government is counting on the new SI 137 of 2016 concerning ITI sharing as the Zimbabwean ICT Policy has little reference to it in its entirety. The ICT Policy only generally states that non-sharing of infrastructure in the sector is wasteful of resources and that telecommunications Providers share infrastructure on a purely contractual basis with the regulator playing a limited oversight role. Companies only agreed to share infrastructure provided there was a commercial benefit accruing. That inadvertently resulted in unnecessary duplication of infrastructure. Ideally, telecommunications operators should compete based on the quality of services provided as opposed to infrastructure establishments. The competition that is currently at play, which is pivoted at who owns what ITI and where, is clearly not sustainable, unfriendly to the environment and the end users.

Figure 1 depicts what the research entails concerning the interaction between the stated concepts and their variables. It unpacks the ideals as well as the reality of infrastructure sharing in Zimbabwe. It formulates a perception as to what the reader should visualize as far as ITI sharing in Zimbabwe is concerned, from the provider to

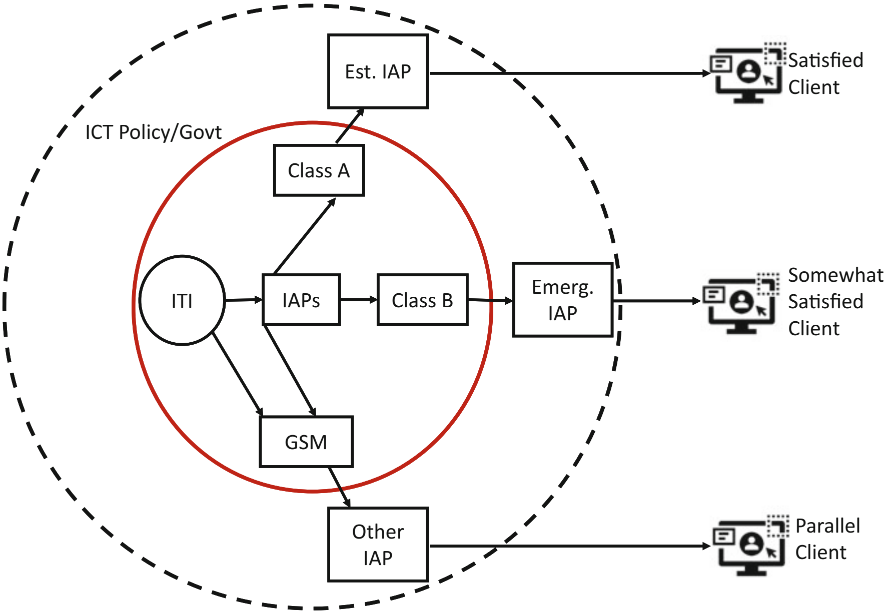


Fig. 1 Conceptual framework for ITI sharing in Zimbabwe. Source: Study

the seeker and cascading down to the end user with all the relevant relationships to concerned government authorities as well. ITI is the main element, and it is classified into Global System for Mobile (GSM) and IAP infrastructure. IAPs assume the role of carrier of carriers by providing access to ISPs, a service also provided by GSMs but not in a large or in this case a major scale. IAPs subdivide into two groups, those that have Class A licensing and Class B licence holders. The relevance of these classes is that Class A licence holders are those firms with higher coverage, or the monopoly of infrastructure as compared to Class B firms which are still establishing a way in the industry.

Most established ISPs get their access from Class A licence holders while emerging ISPs get their access from Class B holders, a development shown to be a current prevailing issue. Several reasons for this were established as will be discussed in the following sections. While some GSM firms have their own infrastructure, others rely on the infrastructures of IAPs. Likewise, most ISPs preferred to access via IAPs rather than GSMs. It was noted that most satisfied clients were users that accessed via Class A licence holders. Users that utilized the services through an ISP that accessed via a Class B licence holder were somewhat not fully satisfied with the service while users that accessed a GSM probably needed to access the Internet temporarily or felt they did not have time to go through the long registration processes before they can use the Internet.

3 Theoretical Approach

This section is dedicated to the theoretical approaches that were employed to examine how ITI sharing can meet citizen needs and maintain a sustainable environment. The establishment that emanated from current sharing deals indicated a lot of discrepancies, unequal opportunities for emerging ISPs, possible disenfranchisement of smaller providers by well-established firms, and other various challenges. What emerged implied that there could be deeper issues than the explanations from a surface level point of view. All those challenges at the end posed a threat to the sustainability of the environment and end user satisfaction, a development that motivated the study to delve into how they can be addressed. Whether in the form of big firms violating town planning regulations in the development of their ITI, or citizens faced with connectivity challenges when providers are experiencing downtimes, cut offs, or renewal of leases, it was shown that human action and behavior are main issues of concern with regard to the prevailing problem (Chowdhury et al., 2020; Zimmermann & Renaud, 2019). As a result, problematization (Bacchi et al., 2010) as a methodological approach was employed to better define the problem space. Bacchi poses six questions in the approach, also better known as the "what's the problem represented to be? (WPR)" approach (Mthwazi, 2021). Customized from Bacchi's six problematization questions and with reference to the research question, this inquiry sought to find out:

1. What is the ITI sharing problem represented to be?
2. What presuppositions or assumptions underlie this representation of the problem?
3. How has this representation of the problem come about?
4. What is left unproblematic in this problem representation? Where are the silences? Can the problem be thought about differently?
5. What effects are produced by this representation of the problem?
6. How/where has this representation of the problem been produced?

After problematizing, it was important to understand the relationships between sharing firms and the individuals affected by those engagements. The inquiry drew from Anthony Giddens' theory of structuration (ST), which states that the structures in which humans find themselves are determined for them by their actions (Brooks et al., 2008; Jones & Karsten, 2008; Rose & Scheepers, 2001). The theory explicates the relationships that the human "agency" has with institutions or "structure." Giddens explains that structure and agency cannot separate; that they connect to one another in what has been termed the "duality of structure." Hence, in this instance, no matter how technical the issues were, the deeper issues were shown to result from human interactions with concerned institutions, in this case the provider, seeker, and citizens. Human actors are the elements that enable creation of our society's structure by means of invented values and norms that reinforce through social acceptance. They are the fundamental element to create new laws that will create or change the routine of society. Consequently, following the human–institution interaction other issues came up during the study. As citizens interacted with service providers for equitable Internet services in some routinized pattern (Giddens, 1984; Rose & Scheepers, 2001), sharing models were built up concurrently. These models evolved from situations that led firms to share their ITI at will or because of compelling circumstances. The models are further explicated in the discussion section.

4 Methodology

The design was preserved in the interpretivism research philosophy, which allows for qualitative inquiry into the respondents' views and experiences about the phenomenon under study. Furthermore, the study employed an inductive approach that allowed the researcher to search for evidence that supports the theoretical implications already inferred by the preliminary observations and the empirical situation (empiricism). Methodological triangulation was employed as the across-method approach allows for analysis of both quantitative and qualitative data (Bekhet & Zauszniewski, 2012). Qualitative analysis was used to explore perceptions drawn from what the stakeholders involved in the infrastructure sharing deals had to say about it as well as the interpretation of the data collected while quantitative approaches were to used draw inferences from statistical data.

Following are the research design steps the inquiry followed, as guided by the research onion (Saunders et al., 2019):

(a) *Worldview*—The inquiry drew from a combination of empiricism and interpretive (Walsham, 2014) epistemological assumptions as it sought to extend knowledge about the ITI sharing phenomenon and its effects on environmental sustainability and the delivery of equitable public services to citizens. While an explanatory approach is used to interpret data from key informant interviewees, the empirical evidence validates the findings using statistics about the ITI sharing issues. A worldview always shapes and determines all other methodological steps that follow in a research inquiry (Guba & Lincoln, 1994).
(b) *Philosophy*—The inquiry followed an interpretivist approach, explanatory in nature as it necessitated understanding the role of structure and humans as social actors (Jones & Karsten, 2008) in what would become ITI sharing effects on equitability of public service delivery to citizens and environmental sustainability.
(c) *Approach to Theory*—The inductive approach was used as the inquiry was highly concerned with the context (Saunders et al., 2019) in which the ITI sharing phenomenon affected citizens and environmental sustainability based on the empirical evidence from the selected respondents. While the ST and problematization were used to sensitize the study toward the argument of interdependence of structure and agency and hence clearly define the problem, more focus was placed on the analysis of the empirical evidence to examine the dynamics of ITI sharing.

(d) *Methodological choice*—Methodological triangulation (Bekhet & Zauszniewski, 2012; Jack & Raturi, 2006) approach was used. This choice was motivated by different types of data that were collected, and how they were analyzed. While the quantitative data were used to draw meaning from statistical data, qualitative methods were employed to identify patterns and themes of analysis in the data collected.
(e) *Strategy*—The research strategy combined the use of key informants in a survey approach.
(f) *Data collection Techniques and Procedures.*

Data were collected with the use of face-to-face in-depth key informant interviews and where reach was difficult, audio diaries and telephone interviews were used instead. Two sets of semi-structured open-ended questionnaires were used, one designed for the ISPs, combining the sentiments of both the users and the business owners or managers. The other was designed for the policy enforcers (regulatory boards). The study interviewed the key informants with the guidance of the questionnaires, recording the respondents' answers to the questions. Respondents who were not comfortable with audio interviews wrote down their responses on the questionnaire. More so, where the respondent would agree to fill the questionnaire themselves, they were permitted to do so. All these methods were employed to preserve the respondent's right to confidentiality, privacy, and anonymity while trying get the most accurate and unbiased responses at the same time.

The study was confined to ten firms that are in the web of ITI sharing deals together with the regulatory boards that govern the uses, management, ownership, development, and maintenance of those infrastructures. The research studied the general Zimbabwean network coverage in terms of broadband as well as GSM. Among firms that provide infrastructure to support these technologies three of the top five and three of the emerging five were in the center of the scope of the study. These companies are Liquid, one of the nation's private and leading IAP, Powertel, a parastatal or government-controlled carrier-of-carriers IAP as well as TelOne which is also a government-controlled IAP. The three emerging Internet service provision firms that were considered are Africom, Telecontract, and ZOL, all of which are privately owned ISPs. A new player Dandemutande (see Table 4) penetrated the market in the year 2017 and by 2020 it had gained and continued to gain a relatively huge fiber market share in the country.

Only two types of regulatory boards were considered in the scope, one which directly falls under the Ministry of Information and Communication Technologies (MICTs) POTRAZ, and the local authorities, which are somewhat independent from the government's decision-making processes but nonetheless fall under their jurisdiction through Acts of Parliament. Data sorting was done manually, as the study gathered unstructured quantitative and qualitative information. Common patterns and themes were formulated. After sorting, data was coded and analyzed using SPSS software.

5 Findings

POTRAZ's report on the Zimbabwe ICT policy claims that there is disjoint utilization of infrastructure by major IAPs, a situation which they claim in the SI 137 of 2016, will eventually lead to duplication of infrastructure. Duplication of infrastructure can only lead to other problems, major ones being exploitation of the end users and environmental degradation.

Table 3 confirms what the desk research established in terms of IAPs with leading market shares in the ITI sharing industry. Only one of the emerging ISPs penetrated the market starting year 2012 showing the difficulty for new entrance into the industry.

Table 4 based on POTRAZ's 2017 report, shows the same pattern although with a bit of emerging ISPs managing to make the list. It is arguable if the advantage that established firms had, was ownership of the ITI, or the monopoly of the ITI highway. Another angle could be that, since the imposition of the SI 137 of 2016 (in November 2016), POTRAZ could argue that the policy paved way for new entrants. Contrary to that, new firms argued that they had been lobbying for so long that the new Instrument had nothing to do with their success in finally entering the market.

Table 4 further shows that emerging firms like Telecontract and Africom had entered the market share, while ZOL was still struggling. While TelOne led on broadband coverage on the nation during the 2013–2015 period, Econet through its subsidiary Liquid went on to develop their infrastructure regionally, a vision that later gave them an upper hand in southern Africa as an IAP. As shown in Table 4, Liquid is currently one of the leading IAPs in the Southern African Development Community (SADC) while TelOne and Powertel follow, respectively.

Figure 2 shows how Dandemutande continues to grow its market share as it draws closer to the country's third largest service provider in the third quarter of 2021 (POTRAZ, 2021), numerical statistics given in Table 5. Figures 3, 4, 5 and 6 show how Liquid's fiber optic map is laid out in Zimbabwe and Southern Africa, Powertel layout as well as Africom's coverage, respectively. What is mainly notable is Liquid's dominance in network coverage. Figure 4 goes on to depict how Liquid has developed its ITI beyond Zimbabwean borders. It shows Liquid's fiber coverage in SADC. Judging with what the maps depict, it follows that Liquid has a monopoly in terms of ITI coverage in Zimbabwe. Africom, on the other hand, seems to be developing around major cities. Dandemutande broadband coverage maps are not available to the public, however their presence is determined by the number of subscriptions as reported by POTRAZ.

Similarly, the network coverage maps provided in the study do not reflect what is currently on the ground but the only latest representations so far. This is part of the future work in terms of developing integrated ITI sharing maps for improved sharing, uses, management, ownership, development, and maintenance.

From a regulator's point of view, a 100% of the respondents said ITI sharing was a necessity for both emerging and established firms. They claimed there was a benefit to both parties if procedures for firms to develop their ITI were well

Table 3 Incoming and outgoing bandwidth statistics from 2010 to 2013

International Bandwidth (Mbps)								
	2010		2011		2012		2013	
	Incoming	Outgoing	Incoming	Outgoing	Incoming	Outgoing	Incoming	Outgoing
TelOne	89	30	942	942	1395	1395	2015	2015
PowerTel	50	50	860	860	930	930	1395	1395
Liquid	100	50	622	622	775	775	930	930
Africom					100	100	190	190

Source: POTRAZ (2014)

Table 4 Market share statistics from 2016 to 2017

	Market Share of IAP Revenues 2016	Market Share of IAP Revenues 2017	% Change
Liquid	50.3%	52.6%	2.3%
TelOne	22.9%	23.0%	0.1%
Powertel	16.8%	13.9%	−2.9%
Dandemutande	5.2%	6.1%	0.9%
Africom	3.1%	3.0%	−0.1%
Telecontract	1.5%	1.3%	−0.2%
Aquiva	0.2%	0.2%	0.0%
Aptics*	0.0%	0.0%	0.0%
Total	100%	100%	0.0%

Source: POTRAZ (2017)

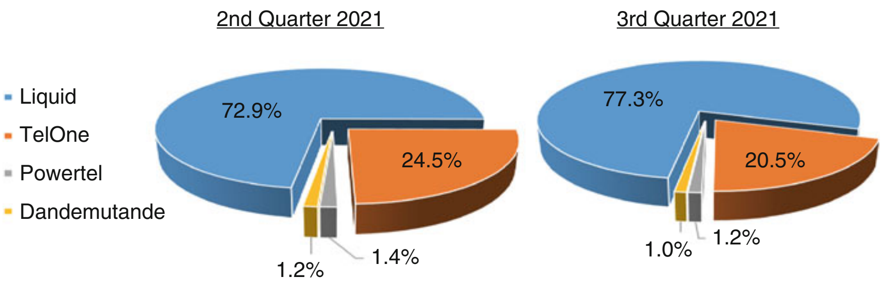


Fig. 2 Fiber optic market share in Zimbabwe. Source: POTRAZ (2021)

Table 5 Market share statistics 2021

	2nd Quarter 2021	3rd Quarter 2021	Variance (%)
Liquid	260,000	330,000	26.9%
TelOne	87,500	87,500	0.0%
Powertel	5000	5000	0.0%
Dandemutande	4161	4416	6.1%
Total	356,661	426,916	19.7%

Source: POTRAZ (2021)

structured. It was expected that no new nor established firm would have any difficulties should they wish to establish ITI. They mentioned that conditions for such establishments were favorable for both small and well-established firms. However, when they were asked on how ITI sharing and owning is expressed in the Zimbabwean ICT Policy, there seemed to be disparities. Further inquiry revealed that Sect. 4 of the Policy (ICT infrastructure) only scraps the surface of sharing and

Fig. 3 A map of Liquid's fiber optic coverage in Zimbabwe. Source Kabezwa (2013)

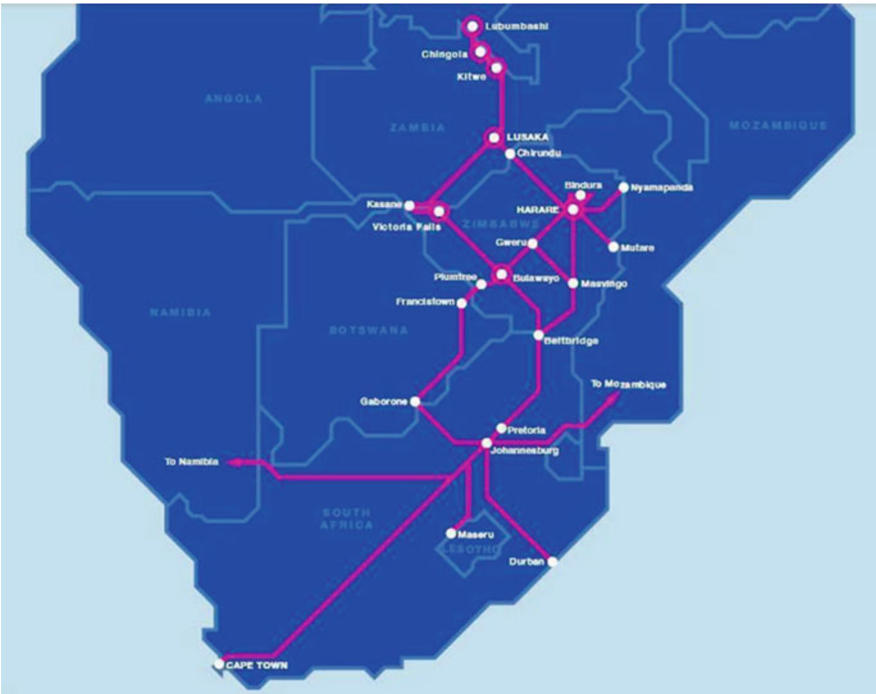


Fig. 4 A map of Liquid's fiber optic coverage in SADC. Source: Kabweza (2011)

Fig. 5 A map of Powertel's fiber optic coverage in Zimbabwe. Source: Kabweza (2013)

ownership. It does not roll out a framework on sharing but rather expresses what the government intends to do in future concerning ITI.

While the government had great ideas on developing and increasing the capacity of ITI, it prematurely imposed the SI 137 of 2016. In the Policy, there were concerns about non-sharing of ITI pointing that the sharing that exists is based on commercial benefits. This development only benefited highly resourced firms and created a network access monopoly for established firms. The government-imposed SI 137 of 2016 then, which has caused uproar among telecommunications companies (Mpala, 2016) (Tables 6, 7, 8).

60% of regulatory boards agreed that the Instrument affects established firms in a positive way. Uproar was caused by mere speculation of what firms thought the Instrument was going to do to their business investments. These boards are the POTRAZ, the Bulawayo City Council, and the Gweru City Council. The Harare City Council was objective on the issue. They recognized the uproar as somewhat genuine, while the Environmental Management Agency (EMA), on the other hand, was not certain of what to make of the development. Further findings discussed next are statistical representations of what the ten firms selected had to express in terms of the Instrument and ITI sharing deals (Fig. 7).

70% of service provider firms viewed ITI sharing as a useful development but Liquid Telecommunications and Africom were uncertain. Liquid Telecommunications was skeptical concerning whom this sharing is useful. Liquid

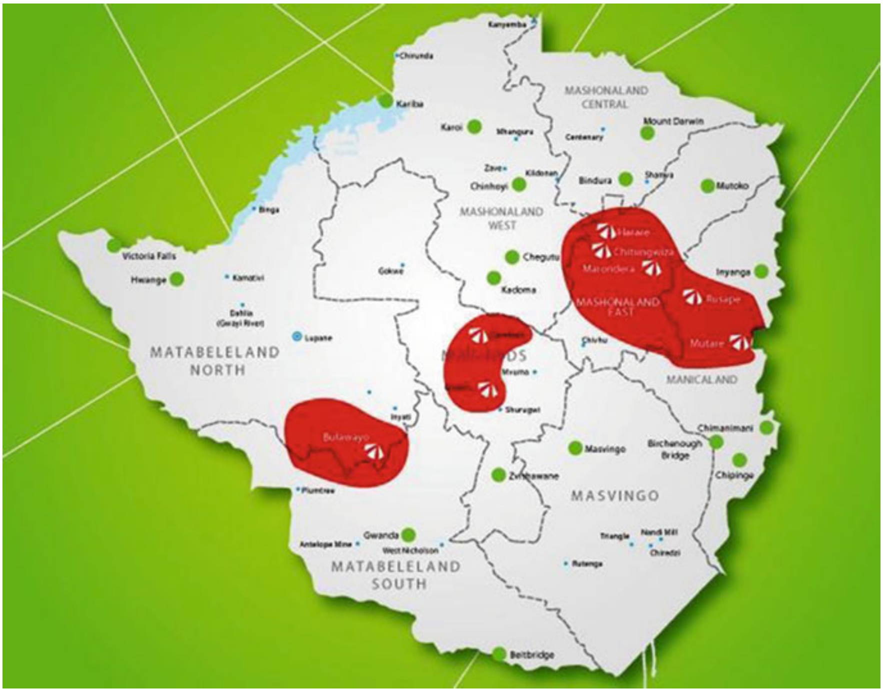


Fig. 6 A map of Africom's fiber optic coverage in Zimbabwe. Source: Africom (2018)

Table 6 Regulatory boards' perspectives of the SI 137 of 2016 and the ICT Policy

Instrument contents in line with ICT Policy					
		Frequency	Percent	Valid percent	Cumulative percent
Valid	Yes	4	80.0	80.0	80.0
	Not sure	1	20.0	20.0	100.0
	Total	5	100.0	100.0	

Table 7 Regulatory boards, thoughts on how Instrument affects emerging ISPs

How instrument affects emerging ISPs					
		Frequency	Percent	Valid percent	Cumulative percent
Valid	Not sure	1	20.0	20.0	20.0
	Positively	1	20.0	20.0	40.0
	Strongly positively	3	60.0	60.0	100.0
	Total	5	100.0	100.0	

Telecommunications were of the idea that they can perfectly survive without sharing while Africom stated that government owned firms are not transparently expressing how they will share their ITI. Telecontract praised a certain clause in the Instrument that states that if a company applies to the local authority with an intention to develop

Table 8 Regulators views about the ingenuity of uproar

Mere speculation causing uproar					
		Frequency	Percent	Valid percent	Cumulative percent
Valid	Disagree	1	20.0	20.0	20.0
	Not sure	1	20.0	20.0	40.0
	Agree	2	40.0	40.0	80.0
	Strongly agree	1	20.0	20.0	100.0
	Total	5	100.0	100.0	

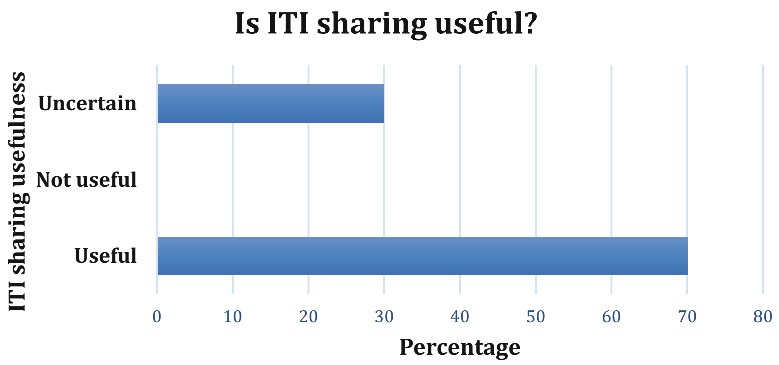


Fig. 7 A depiction of how useful firms think ITI sharing is

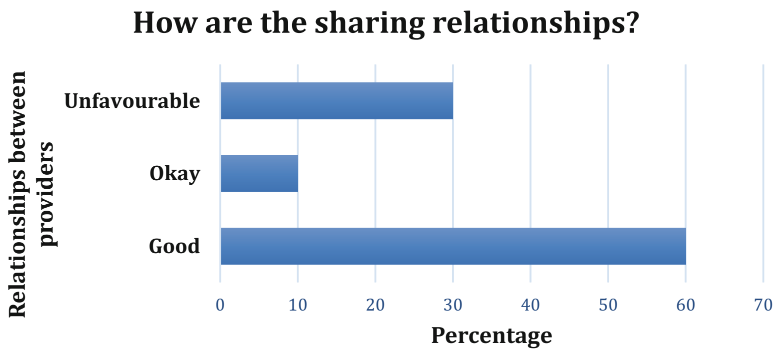


Fig. 8 A representation of the current sharing relationships

ITI, they should receive a response within a month otherwise the Instrument permits them to go on with development (Fig. 8).

Existing relationships among firms did not change much after imposition. For instance, Telecontract has a long existing contractual agreement with Powertel as it used to contract for it. These companies never had any problems with sharing before and were still in good faith after the imposition. Econet, through Liquid its subsidiary

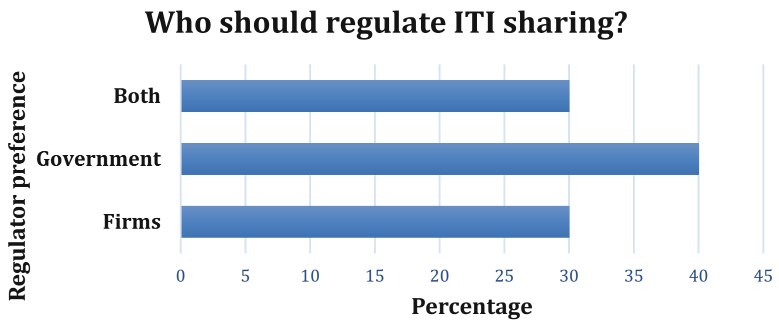
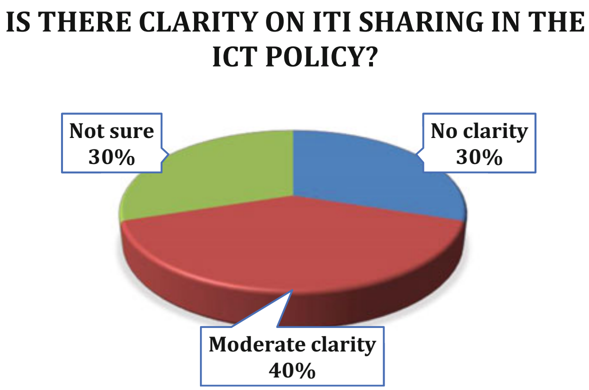


Fig. 9 A depiction of who firms think should regulate ITI sharing

Fig. 10 A depiction of the clarity of the ICT policy on ITI sharing



could not just share infrastructure with firms that did not contribute financially to the development of the ITIs. They claimed the government showed bias toward parastatals by waiving taxes and duty on the ITI, while Econet had to borrow to roll out these projects (Fig. 9).

Four firms agreed that the government should take control of issues of ownership and sharing to minimize exploitation of smaller firms by established ones. However, Telecontract questioned the government's position on that because of its part ownership of some of the providers. For this reason, a couple of companies indicated that firms could manage their own ITI while another couple of companies opted for an arrangement that sees both the government and private firms collaboratively develop, own, and maintain the ITIs (Fig. 10).

Three firms outrightly pointed out that there is no clarity on how sharing will be done, while the other three were not sure if the Policy is the right document to address those views anyway. Four firms indicated that the Policy moderately clarified how sharing will be conducted. No firm confirmed clarity.

6 Discussion

The SI 137 of 2016 objectives were to eliminate duplication of ITI, maximize use of existing infrastructure; minimize environmental degradation through installations by each player that joins the Internet service provision business; promote fair competition so that firms can concentrate on service provision quality instead; promote effective town and country planning; and to ensure sufficient ITI in the country. Some of the ways it is going to ensure this is through exercising licensing and regulatory power in respect of ITI development, carrying out audits, determining categories and sites of ITI sharing in the public interest, direct license holders to share ITI, and enforce technical and commercial standards for sharing. Other ways were to promote transparency and non-discriminatory competitive and cost-effective competition during sharing, encourage telecommunication license holders to upgrade existing facilities to suit sharing capacities, develop an ITI sharing database, and promote open access to ITI.

However, after a close analysis of these objectives it is evident there is nowhere the GoZ as represented by POTRAZ was clear as to how they will assist both established firms and emerging ones in achieving these goals. The GoZ is not ready to assume full responsibility of this endeavor as it should do. For this establishment to work without firms putting each other in difficult sharing experiences, the GoZ must map up a clear financial and material support strategies to both these groups. An imposed directive will only cause chaos in the sharing agreements. For instance, if established providers were expected to upgrade their ITI from their own budgets for the benefit of seekers and the public without financial assistance from the GoZ, this would pose possible exploitation by the provider, where seekers will have no leverage to voice their concerns when networks are experiencing downtimes resulting from financial obligations that lie with providers.

That is not the only disadvantage to the seeker, financial implications will also come into play, where seekers will receive exorbitant bills for ITI maintenance. Providers should be assisted by benefiting seekers, should they experience broken links. With these scenarios at play the degrees of competition are most likely to change but it is still not yet clear to whose advantage. While some organizations argue that ITI is not ideally a competitive advantage to firms, but the quality of their Internet service provisions, other organizations have thought otherwise. Those latter only prioritize on building a strong ITI base first before they worry about the services eventually. Such organizations are aware of the connectivity assurance they have afforded their users hence feel they have the upper hand. They claim the quality of service would not matter if there was no backbone to begin with, the reason why terrorist attacks target infrastructures more than secondary services (Sharma & Gupta, 2002). In other words, these provider firms suggest that instead of governments holding them at ransom for having dominance in ITI, governments should instead make sure providers are secure by providing the necessary security for them and financial assistance where possible to keep the services of a nation up and running at effective and efficient levels.

6.1 Models of ITI Sharing

As mentioned earlier, routinized actions between the human agency and structure (Jones & Karsten, 2008; Rose & Scheepers, 2001) resulted in the formation of some ITI sharing models. These sharing models, namely collaborative, voluntary, and imposed sharing came about through firm agreements (collaborative and voluntary), and government directives (imposed sharing). For instance, when organizations came to a mutual agreement to share the infrastructure, by both contributing to its development, this resulted in collaborative sharing. Some firms were compelled to call up other firms to share their ITI to avoid underutilization. This resulted in the voluntary sharing model. The last sharing model was the one imposed by the government through the SI 137 of 2016. While in discussion with interested parties, it emerged that for the most parts there were discrepancies between sharing firms, as sharing deals differed from organization to organization. Moreover, some firms assumed that by sharing as imposed by the Statutory Instrument, it meant that, any firm can request to ride on any infrastructure. Another assumption was that sharing meant ducts not fiber. Similarly, these assumptions and the implications of the Instrument did not disqualify that it could mean sharing the actual information highway. A simplified analysis based on information provided by the firms themselves was made.

6.1.1 Collaborative Sharing

In Collaborative, one among two or more providers identifies a client base, but because there is already another provider, at small scale, the provider approaches that providing firm for joint development of the infrastructure. This is based on mutual agreements. One example is Powertel and Telecontract. These have a long-standing relationship dating since Telecontract was still a government contractor. Their agreement was based on "use mine, I will use yours," provided there were no obvious violations, especially those that are clearly stated on the ICT Policy. Collaborative sharing to date, is based on understanding whom to collaborate with more than how to maximize profits.

6.1.2 Voluntary Sharing

Firms that held a competitive advantage at a certain location for a very long time ended up over-investing. They developed state-of-the-art infrastructures and increased infrastructure-handling capacity with the hope that should the demand rise, they will be fully capacitated. However, when new entrants entered the market and the firms with highly established ITI started losing market share to the emerging firms, the strategy was to negotiate sharing in the form of let outs, their ITI to the new entrants. The carrier firm volunteered to share with the new firm to minimize underutilization of its already established infrastructure.

6.1.3 Imposed Sharing

The SI 137 of 2016 imposed that firms should share ITI to avoid hustles for stakeholders. Generally, the imposition or the Instrument receives much criticism from both the established and the emerging ISPs. It left some gray areas on the sharing framework. It was not explicit on the aspects of lease rates, penalties, and maintenance. It did not state the regulations on the technological and economic agreements.

6.2 Practical Implications of ITI Sharing

It was inevitable that IAPs and ISPs will eventually need regulated ITI sharing frameworks but for most, it was not expected in the form of SI 137 of 2016. The incremental development of ITI ideally meant two results for the environment and the citizen; 1, that the citizens will enjoy an increased access and affordable Internet service provision, but 2, an increase in environmental degradation both of which are the study's concern. Therefore, the study analytically delved into the two issues to establish common ground and inform the concerned parties on routes to consider in the resolution of such emerging factors.

In terms of:

6.2.1 Examining the Effects of the Current Sharing Deals on Environmental Sustainability

It was evident that firms were concerned about maximizing profits by expanding their ITI coverage especially in densely populated areas. The issues of environmental sustainability did not come as a priority when firms competed for areas to establish their ITI. What seemed to be more problematic was that two or more firms could be found working in the same area to develop ITI there, a development that indicated some discrepancies in local authority systems in allocating these development areas to firms. It was not until environment agencies like the Environmental Management Agency (EMA), started to physically check what was happening on the ground, and reconciling it with local authorities, that allocation systems started to improve. The most prevalent environmental issue was how firms poorly rehabilitated road works after they have laid cable. Other issues were when firms had to clear forests to establish new connectivity. All these had negative effects on the environment but there is hope that the collaborative engagement between EMA and local authorities will soon address the issues.

6.2.2 Assessing the Effects of the Current Sharing Deals on Equitability of Public Service Delivery to Citizens

It has been noted that because of lack of regulatory structures, especially for collaborative and voluntary sharing, there is a possibility of exploitation of one firm by another. For instance, when an established firm shares its ITI with an emerging or new entrant, it might inflate let out rates; present exorbitant maintenance fees; monopolize the existing ITI to their advantage; delay attending network downtimes; and frequently raise letting rates. These were some of the challenges mentioned by emerging entrants like ZOL. In that regard, emerging providers were forced to balance out their costs with the client base, a development that ended up rendering their services to the citizens less equitable.

6.2.3 Identifying Improved Government Intervention Measures in ITI Sharing

The lack of an integrated electronic ITI map is the first important shortfall that the study noted. It has been noted that all firms had their networks mapped with the exception of Dandemutande but all these network coverage maps were not unified to show interconnections as would have been expected. Such a disintegrated representation made it difficult in the first place for local authorities to quantify coverage in terms of which provider and what location. The study noted that the government may commence from that end to create a digitized representation of the national ITI map. All other issues were shown to be highly dependent on the availability of that map to both developers and the regulators.

The three sub-objectives discussed above as posed in the beginning of the study fulfill the study's main objective to examine ITI sharing approaches that promote environmental sustainability and equitability of public service delivery. Though consultations with EMA and careful consideration of citizens' needs, GoZ supposedly put in place the SI 137 of 2016. However, there seems to have been a premature enactment of the Instrument which led to further challenges, issues that were meant to have been discussed with a full representation of the affected parties.

Other challenges concerning ITI sharing emanated from external factors. The SI 137 of 2016 was the epitome of all the challenges, confirming how external political factors play a big role in a business environment. Providers did their best to assure high quality of service to the end user, fast access, but it was not until they aligned themselves with existing policy before they were granted permissions to operationalize their strategies. In terms of the green evolution that is now dominating developmental work, firms had to align with environmental agencies, i.e. the EMA to develop their infrastructures, understand what continuous development implied in terms of the natural habitat and society. Firms had to check their technological statuses, how updates and upgrades affect the environment.

6.3 Synthesis

Given the foregoing, higher level stakeholders, i.e., POTRAZ, local authorities (city councils and environmental management agencies), IAP, and ISPs must go back to the drawing board to strategize on formulating one ITI sharing framework. The framework, with the help of data collected from citizens voicing their concerns will facilitate sharing approaches that promote environmental sustainability and accountability toward equitable public service delivery to citizens. Such an endeavor, because it brings together the concerns of all stakeholders, does not only respond to the main objective as presented in this study, but also informs the government on improved intervention measures; assesses the effects of the current sharing dynamics on citizens; and evaluates the prevailing environmental degradation concerns. Once all these milestones are reached, documented, and critically examined for the benefit of all stakeholders, ITI development and sharing deals will then be set to proceed on an eco-friendly environment, but most importantly, afford citizens affordable standardized services.

7 Conclusion and Recommendations

While sharing includes other firms riding on the backbone of established firms, the owners of the ITI were expected to pay interconnection fees for a service that benefits all parties. Secondly, established firms had not recouped the financial investments they made on developing infrastructure, which they claim in the case of Liquid, were loans they are still paying off to date. Telecontract expressed with concern that state-owned firms do not respond to requests to share infrastructure and their organizational structures are such that there is no responsible individual to address enquiries. This for them was a lack of transparency in the sharing deals. Again, parastatals have credit facilities with the government, a development that affects private firms as they compete with organizations that import IT equipment tax free. This made it hard for private providers to compete in an equitable manner without passing down expenses to the end user.

The inquiry hence established there are many oversight issues concerning this establishment. The financial implications of sharing are still not yet visible. Again, the Instrument has no contingency plan should this imposition prove worse than previous arrangements. Nonetheless, a clear approach at this turn is that firms interested to share infrastructure must show commitment in joint payments of interconnection fees, maintenance fees, and collaborative servicing of loans of firms that borrowed to establish ITI before sharing could even begin. POTRAZ is meant to audit all firms at their areas of operation, familiarize with real-time challenges the firms go through. This exercise places them at a better position to determine what the Instrument has not amicably addressed. Finally, POTRAZ must develop an extensive digitally accessible national ITI map that clearly outlines the current state of infrastructure coverage is in the country. The map should clearly show where coverage is, by which provider, as well as where there is no ITI yet. This would assist even the local authorities to know where need is and how firms that desire to ride on other firms' infrastructure can go about it. Currently, POTRAZ still does not have such a national ITI map.

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A Model for Smart Banking in Mauritius

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Abstract Potentialities offered by Internet-of-Things (IoT) have facilitated the development of several applications in various domains such as smart environment (home, office, plant), social, enterprise, utilities, smart transportation and logistics, healthcare, insurance industry, recycling, agriculture, and breeding among others. The IoT is also making a breakthrough in the banking sector, which is one of the major pillars in any economy for a country. There are different facets that banks have embraced with the evolution of time such as retail banking, investment banking, corporate banking, international banking, and non-banking facilities. The application of IoT in banking sector is creating new opportunities such as personalized services to the customers, better monitoring, efficiency, communication, automation, and better control for the bank, thus enhancing the service quality in the banking sector. Nowadays, most of the banking transactions can be completed with the use of a mobile device. The interconnectedness with IoT helps to capture useful information, thus improving the tracking of each transaction in a more efficient way and minimizing risks for both the bank and the customers. IoT is increasing the confines for innovation in the banking sector, redesigning the customer experience. This chapter describes several smart banking systems and frameworks and proposes a model for smart banking. The model provides an overview of how devices and applications can connect while catering for better communication, data integration, sharing and analysis of data. Finally, the chapter presents use cases showing the application of the proposed model in Mauritius.

Keywords Smart Banking · Internet-of-Things · Frameworks for Smart Banking · Model

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1 Introduction

The IoT is envisioned as a technology paradigm allowing interconnectivity between a network of machines globally (Lee & Lee, 2015). Madakam et al. (2015) have defined the IoT as "*an open and comprehensive network of intelligent objects that have the capacity to auto-organize, share information, data and resources, reacting and acting in face of situations and changes in the environment*." This technology is acquiring immense focus from an industrial perspective. Various authors estimated that there are billions of IoT devices all over the world (Egham, 2017). Laurence Goasduff of Gartner estimated 5.8 billion IoT devices by 2020 (Goasduff, 2019). The exact figure is, however, still unknown in 2022. Five technologies have been identified that have paramount importance in the implementation of IoT-based goods and services and they are as follows (Lee & Lee, 2015):

1. Radio Frequency Identification (RFID): This technology enables automatic identification and data capture by making use of radio waves, tag, and reader. It is used mostly in hospitals and laboratories.
2. Wireless Sensor Network: This system comprises spatially allocated autonomous sensor devices. The latter are well equipped in order to be able to examine both environmental and physical states along with the RFID to enable the tracking of location, temperature, and movement of items.
3. Middleware: This concept comprises software layer interposed between software applications to ease the process of input, output, and communication.
4. Cloud Computing: This model normally enables the user to gain access to a shared pool of configurable resources.
5. IoT Application Software: This application promotes the interactions of device-to-device and human-to-device in a more reliable manner.

IoT is now omnipresent in our daily life; be it from household to companies, the implementation of IoT is propagating. The government of Mauritius has already initiated several projects such as the *Bagatelle Dam Remote Data Logger* project, the *Smart Bus* information system, the *Smart Parking* management system, and the *Air Quality Monitoring* system to monitor air pollution. The implementation of smart cities is also an ongoing project in Mauritius (Government Information Service, 2017). Moreover, the financial sector is one of the sectors where the integration of IoT-based services is becoming a necessity.

The financial sector, one of the main pillars in our economy, consists of firms and institutions providing financial services to local and foreign retail or commercial customers (Bansal et al., 2020). Different industries such as banks, real estate, insurance companies, and investment companies form part of this sector. For an economy to be stable, a healthy financial sector is important. A good portion of this sector's revenue is from banks. With the integration of IoT-based services, the way of operation of the banks is likely to change. As banks usually handle massive transfer, collection, and analysis of data, IoT will have a major influence from which banks and customers will benefit. This will allow bankers to work efficiently and smartly, and increase service quality and revenue for the bank. Since IoT requires the use of devices that are interconnected, banks provide users with mobile applications that can be used to complete most of the banking transactions and allow collection of data.

The rest of the chapter is structured as follows. Section 2 describes smart banking along with the existing systems and frameworks in this domain. Concepts of blockchain and smart contracts in smart banking as well as latest trends in smart banking are additionally described in Sect. 2. A model for smart banking is proposed in Sect. 3 and possible use cases describing the application of the model are explained in Sect. 4. Finally, Sect. 5 concludes the chapter and presents future works.

2 Smart Banking

Smart banking is a form of banking whereby sensitive information regarding financial transactions between the client and the bank are transmitted electronically (Bucko, 2017). This type of banking has gained popularity with the rise in mobile devices and IoT systems. With the broad interconnection of IoT systems, the quality of service of the banking sector can be enhanced. This interconnectedness can help capture useful information, thus improving the tracking of each transaction in a more efficient way (Rehman et al., 2017). Data are gathered from several databases, analyzed, verified, filtered, and reported using several open source software. In doing so, financial institutions get a better insight regarding the market variables, thus enabling better trades (Cuomo et al., 2018). Smart banking has been adopted in many countries such as UAE and Sri Lanka (Alhosani & Tariq, 2020; Nayanajith et al., 2020).

2.1 Smart Banking Systems

This section presents some examples of smart banking systems that adopt the use of IoT devices and sensors.

2.1.1 Smart Bank Locker System

An example of smart banking application is a Smart Bank Locker system. The system is designed in order to recognize and control access to lockers of customers (Giripunje et al., 2017). A three-way verification system is proposed. This verification process includes the use of the mobile application found on the customer mobile phone, fingerprint, and an OTP. This approach is effective as it is difficult to break these three verification steps (Giripunje et al., 2017). The prototype adopts a Raspberry Pi, which is a low cost, small, and portable size of computer board

(Zhao et al., 2015). A Raspberry Pi consists of general-purpose header pins that can be connected to sensors.

2.1.2 Smart Bank Locker Using Fingerprint Scanning and Image Processing

Chikara et al. (2020) describe a smart locker for the banking sector. The locker compares image and fingerprints with data stored in a database. It makes use of a *Microcontroller ATMega32* that emits signal to the lock for it to open. A NITGEN optics-based fingerprint sensor is being used for fingerprint identification along with a fingerprint scanner. For image capture, a webcam is being used. The image is then transferred to the computer via a USB cable. Face detection techniques are applied to the image for automatic identification and verification of the person.

2.1.3 IoT-Based ATM Surveillance System

ATMs have been one of the sources of robberies in the past years. Banks suffer losses due to those robberies. In order to reduce these threats, Jacintha et al. (2017) came up with an ATM surveillance system using IoT. This system is based on embedded Arduino, which is a microcontroller that can manage almost any type of electronic device (García et al., 2017). The system uses different sensors to obtain information such as

1. USB camera to capture the picture of the person operating the system,
2. vibration sensors to verify any suspected activities,
3. tilt sensors in case the person tries to tilt the ATMs,
4. temperature sensors to get the degree of temperature near the ATM,
5. GSM module to communicate alerts.

All these sensors and devices are connected to the Arduino ATMEGA-328 controller (Jacintha et al., 2017).

2.2 Smart Banking Frameworks

This section describes frameworks that exist in the context of smart banking. These frameworks adopt several enabling IoT technologies to realize the concept of smart banking.

2.2.1 IoT Publication and Billing (IoTBnB) Framework

Robert et al. (2016) proposed the IoTBnB framework. The main purpose of this framework is to provide support to the end users who would normally want to publish or sell information to other people involved in the same community. The basic concept for this system to work is that the end-user should have the profiles stored on the IoTBnB system. Five prerequisites are required for this framework, which are as follows:

1. discover and publish IoT information based on the choice of the information providers or the consumers,
2. promote the platform so that the members have the facility to exchange and collect information,
3. provide encouragements for the information providers or the consumers so that the value of information is increased,
4. cultivate a system of competition on pricing so that the information providers can fix their price of information and,
5. devise a concept to protect information and secure money transaction using a wallet system among the members in the community.

The goal of this framework is to cater for all the five prerequisites that have been mentioned above (Robert et al., 2016).

2.2.2 IoT-based Smart Environment

Jerald et al. (2015) came up with an architecture for a Smart Environment based on IoT that can be used in various sectors in an economy such as Government E-Services, Smart Emergency Rescue Services, Smart Banking Services, Smart Health Care among others. Several infrastructures are required in this architecture such as sensor networks and mobile communications. The use of RFID technology has been chosen for transfer of information.

The architecture adopts a new concept known as *IoT Information Kendra*, which infers and processes data extracted through sensor networks and RFID from various sectors in the smart environment. A four-layered framework has been proposed, namely:

1. *Perception* layer: This layer is normally supported by a sensor network, which comprises different sensors, antennas, and readers which are RFID based. These features help in the collection of precise information about objects in various business domains. This information is not limited to temperature, location, sound, heart pulse, humidity, pressure, or climatic.
2. *Data Conversion* layer: The data that have been collected are usually in heterogeneous signals forms which cannot be transmitted to the conventional network for data processing. Therefore, this layer helps in the conversion of the signals

into data for transmission to the conventional network. The middleware part, present in this layer, provides support in this conversion process.
3. *Network* layer: This layer is referred as the transport layer whereby data are fetched for the *IoT Information Kendra* to process them. This layer comprises different components such as gateways and routers.
4. *Application* layer: This part deals with the decision-making process regarding data received from the devices connected to the business domains.

Jerald et al. (2015) also suggested that smarter banking is possible with the use of this framework. It will provide bank facilities like raising security or transaction alerts, locating of ATMs, identification of customers, embedding of debit or credit card with RFID tags, and e-services among others.

2.2.3 Smart Banking Using IoT

Lande et al. (2018) proposed an IoT-based solution for fraud detection in the banking sector. The IoT system comprises four distinct features, namely*:*

1. Sensors/Devices: Sensors capture data from the environment. Sensors can be bundled together as part of a device such as mobile phone, which contains sensors such as accelerometer, GPS, digital camera, and others.
2. Connectivity: The information obtained is then sent to cloud. The sensor or device can be basically connected to cloud via mobile, Wi-Fi or even satellite.
3. Data Processing: Upon reaching the cloud system, the information is processed by a software program. For instance, one can determine if the temperature recorded is within an acceptable range.
4. User Interface: The information sent to the end-user is made available through an alert system, emails, or notifications, for example, a text message in the form of an alert is sent when the temperature in a cold storage is not within the required range.

2.2.4 IoT Framework for the Financial Services Sector

Even though the financial services and banking sector are making use of online systems to enhance customer satisfaction, it has been found that the quality of services could be further improved by making use of IoT technologies. Dineshreddy and Gangadharan (2016) have devised an IoT-based framework so that customers can be provided with targeted offers after carrying out a study of income and balances.

The framework comprises four different layers, namely (Dineshreddy & Gangadharan, 2016):

1. *Device Management* layer: In this layer, data are captured from several IoT devices, namely RFID, wearables, or mobiles via direct (Ethernet or Wi-Fi) or indirect link (Zig Bee gateway) to the Internet. The data are then transmitted at

regular intervals. Data from this layer can be used to monitor purchases made by customers or their locations.

2. *Communication* layer: This layer caters for tasks such as data encryption and filtering. Furthermore, this layer is also responsible for interference avoidance and networking.
3. *Integration* layer: The purpose of this component is to fill the gap between the conventional and the current processing environment to be able to capture all the data domains and types.
4. *Event Processing and Analytics* layer: This layer is responsible for handling the streaming events, which come through. This is also an important component since it is responsible for performing analytics on data, which are being incorporated.
5. *Application* layer: This layer provides services for different types of applications to enable them to communicate with the shared protocol and interface method. Additionally, the purpose of this layer is to send information in connection with performance parameters to the basic layers.

Studies have shown that IoT technologies would provide various opportunities for the banking and financial services sector in the future (Li et al., 2021; Nicoletti, 2021; Putra, 2021). However, this would be a major challenge. The implementation of IoT technology in the banking sector is likely to be the support of legacy IT infrastructure. This would have to be altered in order to simplify complicated systems (Dineshreddy & Gangadharan, 2016).

2.2.5 Analysis of Existing Frameworks

In this section, the various frameworks that have been discussed in the Sect. 2.2 are compared. The IoTBnB Framework focuses only on the billing part of the banking sector. It makes use of a wallet system for secure transactions. Data are collected in order to discover customer preferences. Based on that, incentives are provided. However, machine learning is not adopted for intelligent decision-making (Robert et al., 2016). Jerald et al. (2015) discuss about a common framework for a smart environment using IoT that can be used in different sectors of the economy, one of which is the banking sector. It is restricted to only RFID technology. Infrastructure upgrades are required. The inclusion of RFID tags in debit or credit card is a good initiative but can be costly (Jerald et al., 2015). Lande et al. (2018) have proposed a solution that is more restricted to a part of the banking sector. It makes use of sensors and banking transaction in order to detect fraudulent transactions. Alerts and warnings are also generated based on the findings. This framework analyzes transactions to find pattern and provides real-time monitoring for the bank but does not involve decision-making. It only detects or predicts whether a fraud will occur (Lande et al., 2018*).* The IoT-based framework by Dineshreddy and Gangadharan (2016) is the most appropriate one as it is more focused on banking services. It makes use of different sensors present in different devices and provides the data through the

Table 1 Comparative table

Features	IoTBnB	IoT-based Smart Environment	Smart Banking using IoT	IoT framework in financial sector
Framework is specific to banking		✔	✔	✔
Use of sensors	✔	✔	✔	✔
Collecting data and processing	✔	✔	✔	✔
Inclusion of machine learning/AI			✔	✔
Connectivity	✔	✔	✔	✔
Improved service quality/security	✔	✔	✔	✔

framework. This framework is limited to only customer devices. There are other devices that are present in the bank such as ATMs and POS among others. With the evolution of IoT, new technologies such as chatbot can also be included. A comparative table as shown in Table 1 compares the different frameworks based on their functionalities.

2.3 Blockchain in Smart Banking

The adoption of blockchain has been observed in various domains (Akram et al., 2020; Majeed et al., 2021). It has been adopted by more than 40 banks in Japan (Wang et al., 2019). This section describes how blockchain is being used in the banking sector.

Blockchain is defined as "*an immutable ledger which allows transactions take place in a decentralized manner*" (Zheng et al., 2017). A blockchain consists of a sequence of blocks along with a block header and a block body as shown in Fig. 1. The different components of the block header and block body are shown in Fig. 2.

For creating a blockchain, a first block is created. When creating the next block, the hash value of the preceding block is entered in the Parent Block Hash. If there are changes to a previous block, a different hash code would be generated, thus enabling the participant to know whether the previous block has been tampered. Thus, blockchain is recognized as being tamperproof distributed transaction ledger (Samaniego et al., 2016). Using blockchain, IoT security is likely to improve, reducing data breaches or cyberattacks (Bakar et al., 2021; Wang et al., 2019).

2.3.1 Blockchain and Banking with Big Data

Big data can be used to identify pattern based on customer transactions, thus allowing detection of risky transactions. Hassani et al. (2018) discussed the impact

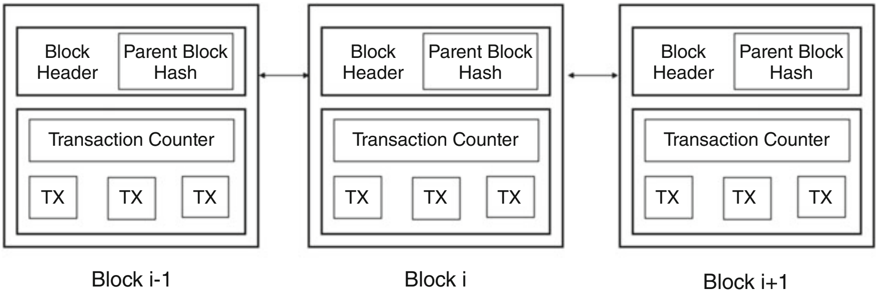

Fig. 1 Blockchain architecture (Zheng et al., 2017)

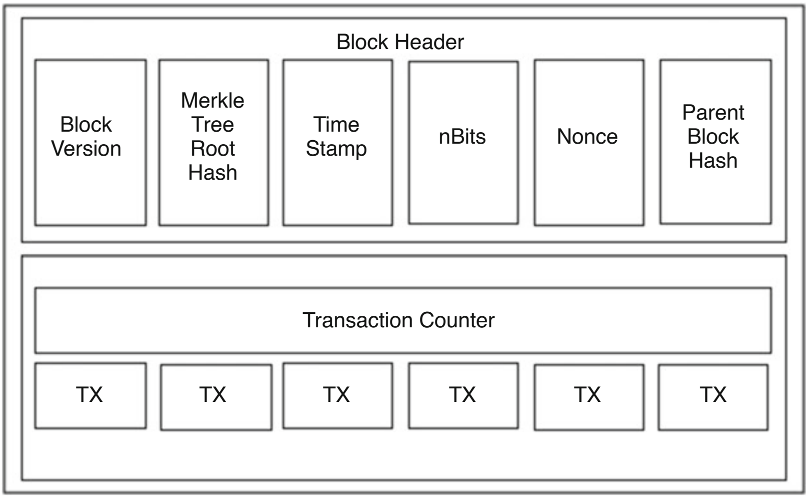

Fig. 2 Block Structure (Zheng et al., 2017)

of big data on blockchain and proposed several opportunities of blockchain in banking. Some are listed as follows:

1. Know your Customer (KYC) is an important task that every bank needs to perform. Multiple regulations from different regulatory bodies exist for maintaining the KYC of every customer as this can help in fighting money laundering (Persistent Systems., 2018). However, maintaining the KYC of customers involves a huge cost. With blockchain, it will reduce duplicate information and allow the simplification of the administrative process as it will enable banks to share customer information across banks. Additionally, sharing information using blockchain will create a non-editable KYC for the customer.
2. With the use of blockchain, payments will be faster than digital payment. Settlement time is reduced enormously using the blockchain technology.

Blockchain will provide a real-time view of the forex to buyers and sellers without any third party for transaction processing.

3. With blockchain, smart contracts can be created. A smart contract is a computer code that is programmed to be executed for creating contracts. It allows financial transactions to take place when the different parties (2 or more) provide the keys and meet predefined criteria (Hassani et al., 2018). Smart contracts are mainly used in trade related transactions.

2.3.2 Financial Loan Management Using Smart Contracts

Wang et al. (2019) came up with a loan on blockchain approach for loan management using the blockchain technology. Since loan management is a single-service mode and involves many stakeholders, most of the transactions are not transparent and cannot be traced. This approach provides a digital account model for ensuring asset transfer. It additionally makes use of smart contracts (chaincode) to lock and unlock and to automatically evaluate or execute a transaction using a permissioned blockchain.

The main components of the model are described as follows:

- *Peer*: Peer is used to run the smart contracts.
- *Fabric SDK Node*: It allows a peer to communicate with the different roles.
- *Channels*: Channels are used to transfer messages between roles and peers.
- *Ordering Services*: Blocks are generated and ordered by the ordering services.
- *Roles*: Every participant is assigned a specific role.
- *Blockchain*: It contains the hash of the previous block with other information such as timestamp and transaction data.

Blockchain-enabled smart contracts have been used in other domains like the architectural, engineering, and construction industry (Hamledari & Fischer, 2021).

2.4 Recent Trends in Smart Banking

This section describes the latest trends with respect to the adoption of IoT in Smart Banking.

2.4.1 Big Data and IoT

Boumlik and Bahaj (2017) have studied the application of Big Data technologies such as Hadoop and MapReduce along with IoT in the banking industry to detect fraudulent behavior. This study proposes an architecture that adopts different devices and objects to share huge amount of data using the Internet and to store the data. The devices and objects consist of sensors, ATMs, smartphones, computers, payment gateways (e-commerce), notebooks, Point of Sale, Contactless, Near Field Communications (NFC), wearables, tokenization, biometric chip, smart kiosk, and smart ATM among others.

2.4.2 Fintech and IoT

Suseendran et al. (2020) conducted a study on how Fintech and IoT can be combined together for innovative ideas in the banking sector. Banks make use of IoT sensor devices such as sensors available on smart phones to collect data about the customer. With the use of Fintech and IoT, the collected data are transformed and stored on the cloud so as to improve e-commerce and to generate more profits (Nicoletti, 2021). Suseendran et al. (2020) listed different innovations in the financial sector such as banking, wealth management, insurance, and capital market.

2.4.3 Digital Trends of IoT in Banking

With the adoption of IoT, the digital revolution has been transformed in the banking sector. Some use case scenarios whereby IoT can be used are discussed as follows:

1. *Wallet of Things:* A wallet can be used to store money without having a bank account and to allow payments through any terminals. A wallet is linked to each device and it allows payment using IoT (Khanboubi et al., 2019; Suseendran et al., 2020).
2. *Account Management of Things*: Biometric data can be used to identify the customer before accessing his banking account. Since biometric data is unique, it provides better security. Wet Ink technology can also be used to clone the physical signature on paper. Therefore, the customer does not need to physically go to the bank. Real-time monitoring of the different collateral is also possible through the different sensors available. The collaterals consist of car, appliances, and machinery among others. In case of impairment, the bank can remotely deactivate the collateral (Khanboubi et al., 2019; Suseendran et al., 2020).
3. *Virtual Money*: Blockchain allows the storage and transmission of information without a central control. It additionally allows the transfer and better tracking of the assets and execution of smart contracts. It also provides better security (Khanboubi et al., 2019).

3 Proposed Smart Banking Model

As discussed in previous sections, IoT in banking comes with a number of benefits for both customers and the bank. With the increasing number of mobiles devices and wearables devices, more data are available. Collecting these data from devices will prove beneficial to banks. Banks can use those data and provide customers with specific services or personalized services as per their needs. Alert generation, chatbot, machine learning techniques, or AI can also be used. IoT in banking will allow banks to decrease their cost and improve customer services and experience (Li et al., 2021; Putra, 2021). Having analyzed the existing systems and frameworks in Sect. 2, this section proposes a model for smart banking illustrated in Fig. 3, taking into consideration the latest trends in smart banking. The different components are interconnected together and are described as follows:

A. *Customer Interaction/External Bodies*

   These components allow the customer to interact with the different devices or external bodies linked with the bank. Some examples include smart watches, desktop PC, laptop, mobile phone, credit card, PayPal, VISA, Mastercard, ATM, POS, other local or international bank, Central Bank, and any other devices used by the bank. Customers can access their internet banking or mobile banking using some of those devices.

B. *Verification and Validation*

   This component allows the verification of devices against the bank database. The registration of the devices is required. Each time a customer uses a device to access its banking data, the device needs to be verified. In doing so, this will increase the security. Additionally, it will allow the validation of any type of transaction that is being performed by the customer with the bank. It also allows the bank to connect to external bodies such as PayPal, VISA, Mastercard, or Central Bank for information sharing.

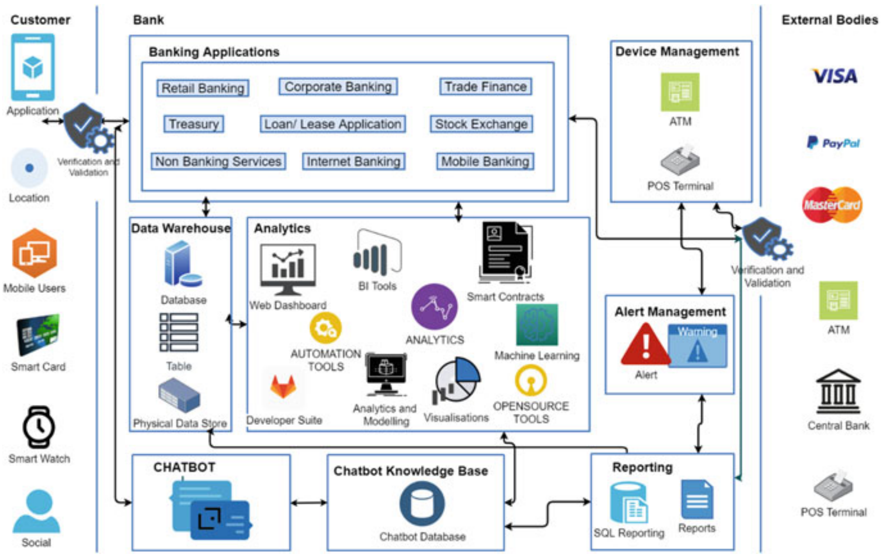

Fig. 3 Proposed model for smart banking

C. *Device Management*

This component provides the bank with the ability to gather information from devices such as ATMs or POS. The ATM, for example, will provide availability status of the device and generate alerts for refill if cash level is below a certain threshold.

D. *Data Warehouse/Analytics/Reporting*

These components will interpret the data received from the different applications or devices and transform them into the required format to be stored in the data warehouse. Based on the data present in the data warehouse, the data will be modeled, and analytics will be performed for decision-making. BI tools can also be used to analyze the data using predictive analytics. Using this information, developers will use developer suite to build models or applications using IoT services. It will provide an overview of the data, services, and analytics of the data with the use of dashboard. Additionally, the data warehouse will be used to generate regulatory reports for the different reporting bodies using business analytics.

E. *Alert Management*

This component will raise alarms. In case there is an issue such as money laundering fraud, it will generate an alarm to the required body for proper actions to be taken or a customer could be alerted based on his financial status, that is, when his monetary stability is threatening.

F. *Chatbot*

This component will allow the customer to interact with a virtual bot that will answer the questions of the customers. As there are different ways of asking the same question and in different languages, a knowledge base will be required. It will store the keywords and possible answers in their respective language. This will not only decrease the waiting time at the bank but will be available 24/7. The use of chatbots will ease the life of the customers, and the bank staff, who will be able to perform other tasks. Social media can also be used to communicate between the customers and banks. Additionally, image processing can be used to gather the information regarding the customer. If the customer wants to open a bank account, the customer can share his demographics such as his birth certificate or ID card, using the chatbot. The chatbot will process the image and fill in any relevant information that is needed. In case there is any missing information, the chatbot can raise an alert to the customer for him to provide this information.

G. *Smart Contract and Blockchain*

This component will make use of blockchain-based smart contracts for Know your Customer (KYC), lending or trade finance related facilities. Smart contracts can be used to access common information during the screening process proving more transparency and reducing administrative costs. For lending facilities, smart contracts will provide a translucent credit scoring and better agreements. Regarding Trade Finance facilities, all details can be stored in the smart contracts providing better transparency and faster service. Smart contracts additionally provide a better customer experience.

H. *IoT Devices*

Since it is a smart banking system, the use of IoT is required. Therefore, for this model the following IoT devices have been identified:

1. Mobile Devices/Smart Phones: Since most of the banks have their own mobile banking platform, the use of the available sensors in smart phones such as proximity sensors or GPS sensors can be used.
2. Smart Card: With the evolution of technology, banks have started to invest in smart cards. These smart cards have an embedded chip on them. There are two types of smart cards: contact and contactless. With contact smart card, the process remains the same as the previous cards. With contactless card, the customers only have to tap this card on the POS and the transaction is done. These smart cards also come with fingerprint sensors.

Moreover, on existing devices such as ATM or POS, additional sensors such as cash level sensors for ATM, proximity sensors for transport that replenish ATMs, and proximity sensors on POS can be installed.

On a final note, the proposed model can be applied to the Mauritian context as several facilities are already present in Mauritius. Most of the banks have their mobile banking application, internet banking, and SMS banking. Mauritius has now become a major international finance center in the Indian Ocean with an estimated total asset size of over US$618 billion as at December 2017 (Ministry of Financial Services and Good Governance, 2019). The financial services sector is of paramount importance in the Mauritian economy, contributing to around 12.1% of the country's GDP and 15% to government tax revenue (Ministry of Financial Services and Good Governance, 2019). This sector is regulated and supervised by the Bank of Mauritius (BoM) and the Financial Services Commission (FSC).

4 Use Cases

This section describes several use cases on how the proposed model in Sect. 3 can be adopted in the Mauritian context.

A customer is willing to take a loan from his bank in Mauritius. The customer first looks for details about the loan. He will search information such as amount allowed, interest rate, and many more on the website of the bank from his devices. The customer can also interact with the chatbot service that is present on the website to get the required information. Based on data that the bank is collecting from his devices or chatbot, the bank will know that the customer is willing to take a loan. The model can then be used to provide the customer with a personalized product. Since the customer now has all the required information, he can then use automatic loan approval application through the bank's website. The customer will fill the web form with the required information. The model will use machine learning or AI to assess the risk factor of the customer, the eligibility of the customer based on the rules set, and verify other information of the customer such as spending pattern. The system will also connect to external bodies such as Mauritius Credit Information Bureau (MCIB) application available at BoM in order to get the customer information. The system can then take appropriate decisions and inform the customer. He can then come to a nearby branch to continue the application. This process will decrease the amount of time used to process a loan or lease. In case the application defers based on established rules for decision-making, the loan application team in the bank can then reassess the loan application.

Moreover, this model is not limited on only the above aspects. Personalized products or discount in certain shops can also be provided to customers based on their geographical location. Predictive analytics can be used for providing customers with personalized products, assess the risk factor related to the customers, assess the spending pattern of the customer, and provide the customer with new products that he is eligible. Based on predictive analytics, the bank can also organize campaigns to promote its products, for example, if a customer is withdrawing money on a certain ATM found near certain shops, discount advertisement can be shown on the ATM machine while the customer is waiting. Additionally, after the transaction is done on the ATM, the customer can be sent messages listing the discounts that are present in the nearby location. Personalized products can also be shared with the customer through internet banking, mobile banking, SMS banking, or can even be printed at the back of the receipt from the ATM machine. If the customer is topping up his prepaid card at a certain frequency every month, the bank can propose the customer with a credit card. In this way, the customer will benefit from more advantages than before.

Furthermore, machine learning and predictive analytics can be used to detect frauds such as money laundering and credit card fraud. Alarms will be raised in case such fraud occurs or is likely to occur. The bank can therefore take necessary precaution or decision to cater or prevent those. The bank can also use IoT to get real-time information regarding the status of the ATM, cash level, and availability report of the ATM. Prediction based on cash deposit or withdrawal on specific ATM can be done in order to avoid cash depletion on ATM. The bank can also use IoT to take attendance of staff through GPS location on their mobile. In order to tackle the security aspects, the bank can encrypt or use blockchain for securing the data being transferred. Use of blockchain will also help prevent frauds. The integration of blockchain can transform the banking world. With its advanced security and ability to share information, such a system will have huge benefits, for example, while updating the KYC of its customers, blockchain can be used as this information will be distributed among other systems. Moreover, through this type of security, the use of the MCIB application hosted by the BoM can allow the sharing of sensitive information such customer name, address, other personal information, and available credit facilities by banks. If ever the system is hacked and the hacker decides to change a certain information, the hash code will also change.

Since smart contracts work in line with blockchain, they can be used in the case of trade finance products such as Bank Guarantee or Letter of Credit, for example, when a customer wants to import a product. With the use of a smart contract, the agreement between the importer and exporter and Letter of Credit between the import bank and export bank can be consolidated. The smart contract will contain all the details of the trade and also the different terms and conditions for payment. When the customer acknowledges receipt of his products, the payment is completed automatically. Smart contracts can also be used for updating the KYC of customers.

Intelligent ATM can also be considered. It includes different security measures. One example is that if the ATM location does not map the geographical location of the customer, the ATM machine can reject the transaction. This idea can also be used for POS. This will provide a better security for the customer. As there is a need to submit regulatory reports to the different regulatory bodies such as BoM and Mauritius Revenue Authority (MRA) among others, the reporting components can be used to automate those reports. Robotics can also be used to automate such process or any other recurrent activities. Another possibility is that the bank can assess the stock market and provide customers with possibilities of investment on shares. The bank can use machine learning to predict safe investment on shares. Based on the customers' available balance in their account, the bank can suggest opportunity for a secured investment to the customers. The integration of this framework is feasible. However, before implementation of such a framework, the different guidelines set by the BoM should be taken into consideration.

5 Conclusion and Future Works

This chapter describes concepts of the IoT and how it can be applied in different domains more specifically in smart banking. It additionally describes existing systems and frameworks in smart banking, along with recent trends in the domain. Moreover, it proposes a model built on IoT for the banking sector. The model shows how heterogeneous objects can interact in their physical environment. Use cases have been described showing how the model will allow banks in Mauritius to create customized applications based on customer needs and enhance quality of service. With the inclusion of IoT, several new opportunities have cropped up in the banking sector. Even if one of the main challenges is the legacy IT infrastructure, banks are ready to remodel it using IoT. These aspects of smart banking will not only provide a better service, but through the creation of personalized products, it will give the customer personal attention. Additionally, the profitability of the bank will be increased. As future works, a conceptual framework will be developed. The framework will incorporate an ontology to represent knowledge shared among objects in a smart banking environment and to enhance interoperability among these objects.

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MoPo sane: Mobility Portal for Health Care Centers

Aina Andriamananony and Benjamin Wagner vom Berg

Abstract The project "MoPo gesund—Mobilitätsportal für das Gesundheitswesen" (MoPo sane—mobility portal for the health care centers) is an example of a smart mobility system that provides a solution for flexible and networked mobility in order to improve the accessibility to health centers, especially for rural areas. Essential facilities of the health services (clinics, medical specialists, etc.) are located at the middle-order and/or higher-order regional centers with high traffic. In the era of the advanced Telemedicine (Projekt-Telepflege, 2019), outpatient and inpatient stay in health care facilities will continue to be indispensable in the frame of health care and services of general interest. A web-based and a mobile portal will be used to collect the mobility needs of patients, visitors, and employees with no or restricted individual mobility options (older people, young people without driving licenses, socially disadvantaged people) and connect them to sustainable mobility alternatives. The portal will offer a clearly defined regional backdrop with "mobility endpoints" that can be clearly located from a geographical location. The consideration of such system boundaries has significant advantages. Providing the necessary mobility services would be difficult if the sources and destinations of the paths covered by rural residents are weakly concentrated or widely dispersed. This project will concentrate the mobility endpoints onto various healthcare facilities.

Keywords Sustainable mobility · Smart city · Mobility portal · Health care · Ridesharing

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1 Introduction

Smart mobility solutions are not only digital solutions but also facing sustainability issues in all three dimensions: social, economic, and environmental (Deutscher Bundestag, 1998; Wagner vom Berg, 2019). This means they are environmental and climate-friendly, e.g., by using electromobility or multimodal approaches to be mostly emission-free. The need to fulfill the mobility requirements of current and future generations in a fair way in terms of access and cost, e.g., by using sharing concepts like ridesharing or car-sharing. In the environmental dimension, the need to be load bearing, workers need fair pay and conditions (e.g. bus or cab drivers). Digitalization is the main enabler to make the solution possible.

The MoPo project (https://www.mobilitaetsportal.org/) addresses specifically the mobility to health care centers in a regional traffic system. Essential health care facilities, in Germany, are generally located in medium-sized and regional centers. The (digital) support of the reachability of these health facilities is the focus of MoPo project.

In the following, these facilities will also be subsumed under the term "healthcare centres" and will include, for example, hospitals, rehabilitation clinics, outpatient day clinics, specialist medical clinics, etc. The centralistic structures of modern health care systems impel citizens to be increasingly mobile, especially in rural areas. This also applies to the model region Oldenburg - Wesermarsch, which is the focus of the project. Medical specialist care in the district of Wesermarsch, e.g., is only available in the towns of Elsfleth, Berne, and Lemwerder. Inpatient medical care is available within the Wesermarsch in the Brake middle center in the St. Bernhard Hospital (https://www.krankenhaus-brake.de/). More comprehensive medical care, especially in the form of special clinics, is only provided in the main centers of Oldenburg, Bremerhaven, and Bremen (Bundesministerium für Verkehr und digitale Infrastruktur, 2018).

In addition, demographic trends (due to declining population numbers and an increase in the proportion of the population over 65 years old) will lead to an increased number of journeys for medical purposes. In the more rural regions of the Wesermarsch, such as Elsfleth (Oberzentrum Oldenburg), the proportion of people over 65 will increase by more than twice (Kröcher & Barvels, 2017). This means that not only longer journeys to the health facilities can be expected, but also more journeys for medical reasons.

2 Problem Description

2.1 Current Status

By 2016, there were approximately 700 million outpatient medical cases, and 19.5 million inpatient stays in Germany (Statista, 2019). This is more than 8 "trips" to a health facility per citizen per year. If furthermore, it is assumed that most of the patients regularly receive visitors during their stay; a high number of further trips to health care facilities can be expected. At the same time, visitors, and patients, especially from rural areas, are usually dependent upon their own cars.

In the Wesermarsch model region, there is “rather poor public transport development” for health-oriented events (Bundesministerium für Verkehr und digitale Infrastruktur, 2018). Public transport is mainly provided for school transport. This means, by implication: young people are not able to reach health centers on their own. More than 800 employees work in clinics on average—thus there are corresponding mobility needs here as well. The hospital “Evangelisches Krankenhaus” in Oldenburg has 1400 employees, which is above the average. Even though they have their own parking spaces for employees, the situation is exacerbated by the central location in Oldenburg’s city center. The situation is becoming more acute for the Evangelical Hospital due to the practical lack of visitor and patient parking places, leading to considerable search traffic within the area.

It can be clearly deduced from above that for certain population groups, the mobility, related to the accessibility of health centers, is very challenging:

- The people in rural areas have no access to a car, either without a driving license or without a car.
- Children and adolescents without a driving license.
- Older people that, due to health restrictions, are no longer able or willing to drive a car.
- People with mobility impairments cannot drive themselves due to, e.g., physical impairments.
- Healthcare employees commute long distances to and from work on a regular basis and are consequently exposed to additional financial and physical stress.

The target groups within the framework of “Social Innovation” addressed by this project are, therefore:

- Low-income people.
- Children and adolescents with medical needs, but also as a visitor, e.g., from (elderly) relatives in hospital.
- Older people with an increased need for care, on the one hand, and an increased need for visits on the other (e.g., to visit their partner in hospital).
- Heavily strained health care workers with relatively low incomes, e.g., in the context of care professions.

2.2 Sustainable Approach

Based on this starting point, the project’s central objective is to noticeably improve the mobility of these target groups. This goes hand in hand with a reduction of single trips and the use of sustainable means of transport. As a positive side effect, the amount of traffic in the regional transport system will be reduced.

To achieve this goal, a mobility portal in terms of a multimodal traveler information system with focus on sustainability tailored to the specific needs (Kramers, 2013; Yamaguchi, 2002) is to be designed and prototypically implemented. Furthermore, the development of permanent networks around the topic of patient mobility in the model region is in focus. Within the project, a detailed conception of the portal and the corresponding business model will be developed first, primarily including the outlined network (see below) but also the intended use. Based on the concept, a prototype will be developed which will be tested in a pilot project with clinics and municipalities in the district Wesermarsch. The Wesermarsch region is a rural area and has a high density of elderly citizen. It also has a poor public transportation system. The mayors of Brake, Elsfleth, and Ovelgönne committed their support and participation.

For this purpose, the project focuses on city—surrounding countryside relationships and exemplifies mobility needs from the Wesermarsch district to the health facilities in the district and to the facilities in the "Mittelzentren" Stadt Brake and Stadt Nordenham. Several institutions on municipality level, mobility providers, and health care centers are part of the project.

Some of these institutions were already partners in the project "ZMo target group-oriented mobility chains in health care" (Wagner vom Berg et al., 2018), as part of the mFUND program, funded by the BMDV (Bundesministerium für Digitales und Verkehr). The key partners from the project applied here were also the key partners in ZMo.

The Wesermarsch is also a very suitable model region because it faces various challenges in the field of mobility resulting from topography, population structure, and distribution as well as the existing transport infrastructure (Bundesministerium für Verkehr und digitale Infrastruktur, 2018). Insofar it has already been the subject of various research projects. These include the BMDV model project "Long term security of supply and mobility in rural areas" and the project "NEMo—Sustainable fulfillment of mobility needs in rural areas" funded by the Volkswagen Foundation (www.nemo-mobilitaet.de).

However, a suitable mobility portal for the specific target groups here as well as a procurement system addressing the existing system boundaries of the health care system is still missing and represents a real innovation at the national level. In this context, the system boundary is defined as the framework of the specific mobility system, which results from starting and destination points, mobility requirements, regional transport infrastructure, mobility offers, etc. Comparing the regional mobility system (e.g. of a city), there is a multitude of target groups or little specified target groups, a multitude of different mobility needs, no specific endpoints, and different transport mode choices.

An individual health center (e.g., a hospital) is considered in the case of health centers; this means a significantly increased ability to plan and increase efficiency with a focus on the limited parameters mentioned. For instance, specific passengers with the same aim can be identified regarding the organization of carpools. The primary goal of a corresponding mobility portal must be the facilitation of the arrival and departure of employees, patients, and visitors. In general, this also requires relief of the traffic situation on the way to and in the direct surroundings of the clinics.

That is why the portal must support travel by public transport first. It should be considered, however, that there is usually no adequate public transport connection available, especially when traveling from rural areas (see above). Ridesharing, which must be supported by the portal, is an essential supplement. This also relieves the regional or local traffic situation compared to individual journeys with one's own car and reduces emissions of harmful substances and CO_2 enormously.

3 Social Entrepreneurship ICT Solution

3.1 Portal Features

Ultimately, the project is innovative in several aspects as it has specific characteristics:

1. It addresses the mobility needs of specific target groups in the health sector and improves them.
2. It addresses a clearly defined regional backdrop with "mobility endpoints" that can be in geographical terms. The consideration of such system boundaries has significant advantages. If the sources and destinations (!) of rural residents are poorly concentrated or scattered over a large area, it would be more challenging to provide the necessary mobility services. The mobility endpoints are focused on the respective health facility in this project. Intermediary services are correspondingly efficient, and the available services are fully considered.
3. From points 1 and 2, we can hope for solid participation. This participation is decisive for the success of a mobility portal since prosumer approaches such as ridesharing require a critical mass of participants to ensure effective operation. It will be put to the test in the project's test phase.
4. Using the clearly defined target group and the specific environment, it is possible to manage the platform's marketing effectively, for instance, directly via the communication channels of the clinic, but also via affected general practitioners and specialists.
5. Because of the Covid-19, the users will be asked about their vaccination status before the trip. They will be then asked to bring negative tests if they are not vaccinated.
6. The graphical user interface is specially adapted to the target group's needs. It has been developed as a bachelor thesis. The bachelor student did interviews with older people and made the basis of the mobile design. Since many users are older people, the user interface must consider this. Therefore, further research is done, and the prototype is developed and tested in cooperation with test persons belonging to the target group. As seen in the Annex, the layout is clean and

straightforward to understand, the buttons are large enough, and there are no unnecessary styles or colors used.

The portal will also consider other health centers' specifics to provide optimal mobility. For instance, a distinction of sections in vast hospital areas (e.g., Klinikum Oldenburg (https://www.klinikum-oldenburg.de/) with various entrances for the general clinic, children's clinic, etc.).

3.2 Comparison to Existing Portals

These five characteristics are innovative improvements over existing mobility platforms and portals resulting from practical experience and research. Many years of own research experience in this field have shown that the lack of these properties is the reason for the failure of many of today's existing approaches or that they are only carried out with moderate success.

It also distinguishes itself from existing multimodal mobility portals or apps such as Jelbi from BVG (Jelbi, 2021) or research projects such as the NEMo platform (Nemo Mobilität, 2019) in that it focuses on health centers (see P. 2 for advantages of system boundaries) and strives for a less complex but more robust and easy-to-use solution.

With ride-sharing platforms such as flinc (Flinc, 2019), on the other hand, the critical mass of users for a successful car-sharing offer is not reached, especially in rural areas. The lack of visibility and difficulties in marketing the service can be identified as problems (see P. 4).

This approach is new at the regional and national levels because it has a single destination point. The regional importance is particularly significant in Lower Saxony because of its high number of rural regions. Nevertheless, the approach is also easily transferable at the national level because of its flexibility and the genericity of the model used during the modeling.

4 Research Method and Conduct

The project itself will follow a design thinking approach. The Design Thinking approach aims to bring together the most diverse experiences, opinions, and perspectives possible regarding a problem. The basic assumption of Design Thinking is that innovation arises at the intersection of the three equal factors: "human," "technology," and "economy." Therefore, the approach addressed in the project combines attractiveness (for both end-users and operators), feasibility (from a technical and organizational point of view), and economic viability. From understanding the current needs and requirements of the target groups, prototypes will be implemented and evaluated at an early stage in the planned project by early creation

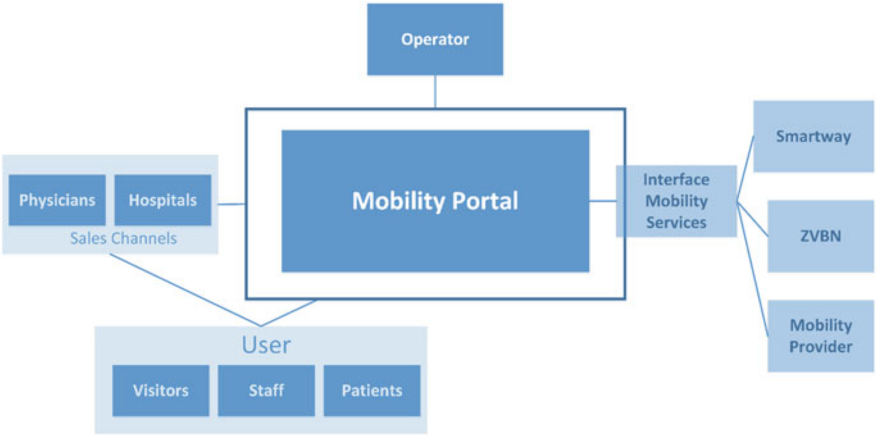

Fig. 1 Portal architecture (Wagner vom Berg, 2019)

and testing. At the same time, the focus here lies more on collecting such insights and experimenting with situations that can improve the planned prototypical offer than on the detailed elaboration of all theoretically possible mobility portal offers. The following phases, partly alternating, will be run through for the process model variant of Design Thinking. The approach improves access to health services and safeguarding services of general interest for the target groups. This is where the mobility portal presented here comes in; it aims to secure access to physical medical services in the future, insofar as these cannot be covered by mobility-sufficient or virtual medical services. The architecture of the portal is shown in Fig. 1. with its main stakeholders and interfaces.

The portal thereby represents a web app through which suitable mobility offers can be found—and can be used. In the minimum case, a start location (or a destination location if head back home from a healthcare center) and a time must be specified. As an example, a ride-sharing opportunity will be identified on this basis.

In addition to ridesharing, public transport services and other mobility options can also be made available. Compared with existing mobility platforms, a particular success factor is the clearly defined deployment channels and the specific target groups for the platform's services.

To achieve the success of the mobility portal in terms of supporting the target mentioned above groups, the five characteristics must be consistently implemented (see Sect. 3.1). For this reason, the mobility portal should also enable communication through a call center so that people with no digital infrastructure can also use it. For example, these can be, e.g., older people or people living in outlying areas with no Internet access. In particular, the portal promotes the mobility of people without a car (older people, young people, the socially disadvantaged). It primarily provides mobility services based on public transport and ridesharing. At the same time, it enables the inclusion of specific needs (e.g., taking a wheelchair with you).

A typical use case could be illustrated as follows:

Cataract surgery is among the standard operations in Germany, with around 800,000 procedures per year. When a patient is diagnosed with cataracts, the clouded natural lens is generally removed as part of an outpatient operation. The patients are not allowed to drive their car on the day of the process and in the following weeks (due to limited or non-existent insurance cover). This often leads to complications in traveling to specialized clinics (some of which are far away). In addition, renouncing one's car, especially in rural regions, is often seen as harming existing opportunities to guarantee services in general. Such a circumstance usually creates interest in third-party mobility services. The mobility portal addresses this demand if necessary. Public transport represents an important alternative. The VBN (Verkehrsverbund Bremen/Niedersachsen, https://www.vbn.de/)/ZVBN (Zweckverband Verkehrsverbund Bremen/Niedersachsen) API (Application Programming Interface) is integrated so that the information concerning public transport can also be shown as an option in the app. To buy a ticket, the user will be redirected to the VBN/ZVBN home page with a pre-filled form. However, as shown above, public transport is not always available, especially in rural areas. Ride-sharing services are, therefore, an essential complement. Thanks to the precise system boundaries (see property 2, Sect. 3.1), their probability of success remains high since the goal remains the same for all users (e.g., hospitals). At the same time, the involvement of "travellers" must be ensured, and appropriate reward systems established (Wagner vom Berg et al., 2016). A general willingness to participate, on the other hand, can be derived from the same destination (see property 3, Sect. 3.1). In addition, minors' safety actions must also be implemented (e.g., unique identification of drivers). Otherwise, barriers against further participation will arise due to corresponding safety risks. In this context, the prevailing data protection law must also be considered, specifically for mobility portals (Wagner vom Berg, 2015).

The Ridesharing system will be based on the design from the COSMO UG. The system offers powerful algorithms in comparison to other solutions—and enables the integration of diverse parameters. An adaptation of the plan envisaged here is required within the framework of the project. The interfaces for connecting the routing System and ZVBN services are designed to be so open in such a way that switching to other providers is easy. This enables transferability to another area and the integration of further mobility providers (e.g., taxi companies).

As already mentioned, users of the portal will be mainly patients, visitors, and clinic employees. While patients and visitors tend mostly to travel to the clinics one way, employees usually travel regularly. This circumstance has to be considered during the design phase. For instance, in the case of ride-sharing services, they are generally suitable for all three user groups, but for employees, the formation of regular carpools must be supported. Furthermore, employees' access to the portal should also become more accessible, e.g., by linking them to the corresponding operational information systems to increase participation here (see properties 3 and 4, Sect. 3.1). Through the involvement of employees, the project also makes a positive contribution to the topic of "The changing world of work." The adaptations mentioned earlier thus improve mobility to health centers for specific target groups/ groups or even make it possible.

According to property 4 (see Sect. 3.1), clinics represent not only the primary goal in this model; they are also an important distribution channel in conjunction with the medical profession. This ensures that the mobility portal for the specific health center gains as much attention and awareness as possible from patients and visitors, e.g., by placing an appropriate announcement on the clinic's website, flyers, or digital information on referral by the doctor. In addition to a website address, leaflets also contain a telephone number (see above). It is also planned to add more languages in the applications later so that migrants can use the service.

Earlier research projects such as the "IKT Plattform" project within the framework of the "Schaufenster Elektromobilität Niedersachsen" have shown that the operator question should be the central point to transfer a portal or platform developed in the context of research to the real world and to establish a long-term basis on it (Wagner vom Berg, 2015). Therefore, a thorough analysis of possible business models and the development of a specific business model within the framework of the project is also planned.

4.1 IT-Architecture

The Architecture of MoPo is based on the Google Cloud Platform. Cloud Technologies enable flexibility and scalabilities without worrying about SLAs. The infrastructure is implemented as a code and can be migrated to other cloud solutions if needed.

As shown in Fig. 2, the Architecture enables the integration of Multiple Healthcare centers and Mobility Providers using adapters. To integrate a Healthcare center into the System, they would have to go through a process and meet some conditions; the same goes for the Mobile Providers. Once in the system, the matching Algorithm will manage the journeys by taking different constraints into account. Smart mobility provides us with a service for optimizing routes in real-time. It would be essential to mention that all the Data collected by the system will stay in Germany as we use Google Data Centers located in Germany. All the data are encrypted before going into the Cloud.

5 Conclusion and Future Challenges

The portal can address the specific needs of different target groups regarding mobility to health care centers. Especially the mobility demands of people, with technological ineptitude, in rural regions can be fulfilled. In the ecological dimension, emissions can be expected because of sustainable mobility options like public transport and ridesharing.

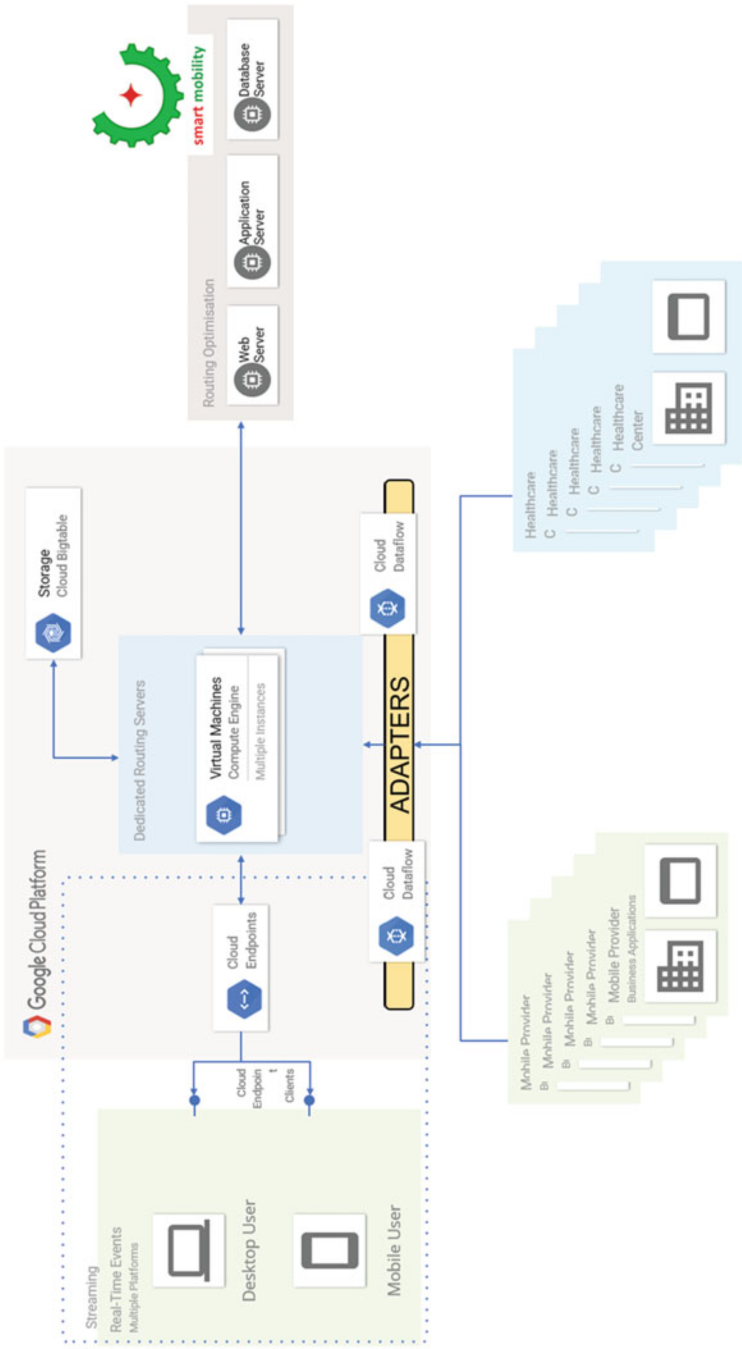

Fig. 2 MoPo-IT-Architecture (Andriamananony, 2019)

A prototypical implementation and a pilot are planned in the Wesermarsch region. The project results should continue to be used after the end of the project and can be economically exploited. To this end, the project addresses different work contents and effects that can be used separately and can also be integrated:

1. Evaluated mobility needs from specific target groups in the health sector and the derived requirements for a functioning mobility platform can be used to implement model development within the study region. It is also expected that the results will be easily transferable to other regional backdrops or scalable without significant adjustments, as a multi-client capable system is to be designed.
2. The idea, respectively, is that the technical implementation concept for the mediation of mobility services (too concentrated endpoints) can be transferred to other application contexts. It can be used for significant events, amongst others, or in different sectors of general interest.
3. The prototype developed and evaluated in the project may be readily adapted not only by the actors involved but also by other actors (in the study region and beyond). It represents a solid basis for developing a marketable mobility portal as a follow-up to the project. The developed concepts will be freely made available.
4. An essential success factor in implementing an economically viable mobility portal will be the derivation resp. establishment of a suitable operator and business models. Various innovative supplier co-operations and operator models are conceivable, which will be investigated during the project. The possible realization and transferability of the models will also be closely examined. The adaptability and transferability of the models are also expected.
5. The participation and involvement of various stakeholders in the project itself is a requirement for the project's success. The stakeholders provide essential information on the optimal design of the offer and can be a starting point for achieving a critical mass of participants for successful operation. Especially prosumer approaches like ridesharing requires a critical mass. The forms and contents of cooperation established in the project could be continued in the addressed research region and transferred to the other areas.
6. COSMO and Ecco will take up the experiences from the project in the data cantered mFund program of the BMDV and incorporate them in planned projects: The mFund program focuses on mobility-related data traffic flows and services within the scope of Open Data. On the one hand, the planned data platform should provide data for regional traffic management and provide forecast and real-time data to improve mobility services. The mobility portal conceived here could be an essential data provider for related data platform services (of course, considering all data protection conditions). COSMO and Ecco have already completed a preparatory feasibility study in 2017/2018 (see Sect. 2.3).

Acknowledgements The MoPo project is funded by European Union Social Fund within the program "Soziale Innovation" and has a budget of 599.860 Euro. The project started in March 2019 and will end in May 2022.

Annex (Screenshots of the App)


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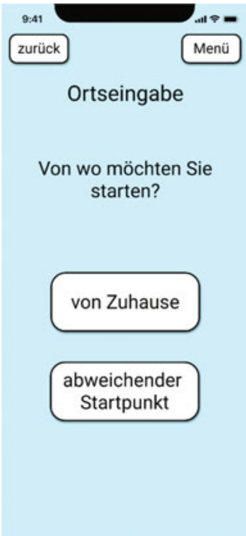
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Tel.: 0441 403-2302
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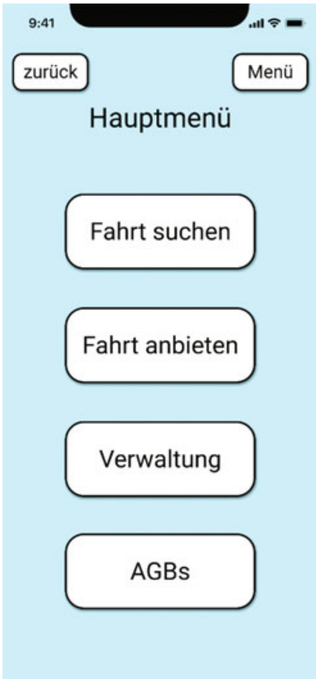
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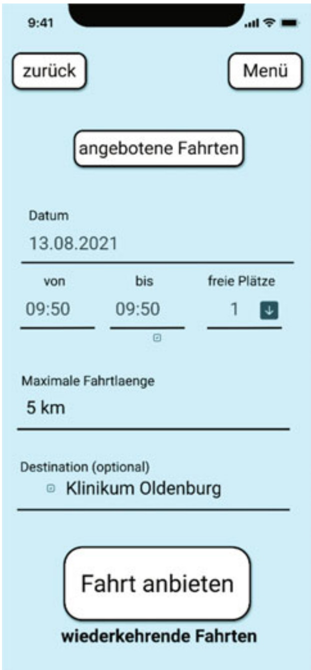
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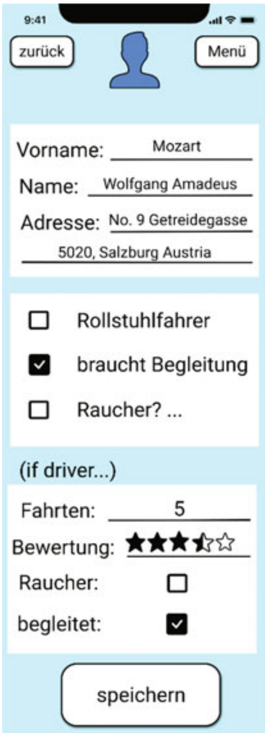
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Part II
Sustainable Entrepreneurship in the Framework of ICT

Computer Technologies for Promoting Women Entrepreneurship Skills Capability and Improved Employability

Abiodun Alao, Roelien Brink, Wallace Chigona, and Edda Tandi Lwoga

Abstract The lack of women's leadership capability in the employment market has contributed to a high rate of unemployment, particularly women are less likely to attain improved employability and/or entrepreneurship skills or take part in their associated benefits due to a lack of digital skills. For this purpose, the study objective is to examine how technologies can promote women's entrepreneurship capabilities and employability. Digital skills development is essential in the labor market, as expected, given the current digitization across all sectors. Hence, to eliminate poverty and improve employability, it has become imperative for more women to become technologically skilled to manage their private enterprises. The Individual Difference Theory was used as a theoretical lens for this study. While semi-structured in-depth interviews and focus group discussions were administered to 59 female respondents, the case study method was utilized to achieve a deeper understanding of the intricate phenomenon and context of the research which is a significant ICT4D study. The key findings of this study revealed how women utilized technologies to achieve improved employability, entrepreneurship capability, and economic development. The study provides recommendations to the government and private organizations to support gender equality, technology inclusion, and women entrepreneurship for improved employability.

Keywords Digital skills · Employability · ICTs · Internet-enabled ICT center · Women entrepreneurship

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1 Introduction

The development of women's entrepreneurship skills is relevant in developing countries especially as the unemployment rate has increased causing poverty due to socioeconomic factors. Therefore, there is a need to consider creating programs that promote digital skills for the improved employability of women (Agarwal & Lenka, 2018). Women living in remote areas are marginalized and experience various challenges with regard to employability (Alao et al., 2017). Women living in remote areas encounter challenges such as unemployment, lack of digital skills, low educational levels as well as societal and economic factors that hinder these women from realizing the benefits of improved livelihoods. This is contrary to their counterparts living in urban areas who have more opportunities to be competitive. Studies have shown that there are limited effective development tools to enable the empowerment of women (Brush & Cooper, 2012; Mosedale, 2014), especially in developing countries where women face socio-economic challenges and miss out on the benefits of industrial and technological development (Nussbaum, 2014).

Many women residing in urban areas work in pink-collar jobs in contrast with professional and technical positions (Stark et al., 2020). Given that more women are involved in professions regarded as extensions of the traditional female roles, women's representation in senior management positions and other professional levels remains low (Zikode, 2020). Nevertheless, despite the level of commitment, talent, and education, career-oriented women in South Africa constantly fight misconceptions and stereotypes that have hindered their upward professional mobility and progression (Erasmus, 1998; Meyer & Landsberg, 2015). The apartheid era and the introduction of the country's democratic system have allowed the emergence of rights and policies supporting women's empowerment. South African women are pursuing careers in big organizations and have increased political ambitions such as ministerial and parliament positions. Therefore, the absorption of females into the IT sector is slowly decreasing due to the lack of digital skills in many technical fields (Zikode, 2020).

1.1 Research Problem

There is an increasingly high unemployment rate in South Africa due to a myriad of factors including the lack of technical and technological skills that are required in the labor market (Alao et al., 2021). Especially in remote areas, there are contributing factors such as contextual, societal, and economic challenges that hinder many women's ability to use technologies for personal advertisement and employability purposes. The young female cohorts between the age group of 25 and 44 and with limited education bear the highest brunt (Wakefield et al., 2020). At least 30.9% of the female population are unemployed compared to 27.7% among their male counterparts Statistics SA (2020a). Based on these findings, it is crucial to develop a strategy involving a practical-based learning process using digital skills at the grassroots level. These skills can allow women in these vulnerable groups to develop well-defined digital knowledge which can assist them to operate their small business enterprises. They may then be able to also apply for employment opportunities to alleviate poverty challenges resulting from the high rate of unemployment (Alao et al., 2021). This study's objective is to promote women's entrepreneurship, digital skills, and technology inclusion for improved employability in remote areas.

Increasingly women's entrepreneurship is considered an antidote to unemployment, it has the potential to make a great impact on innovation, employment, and wealth creation (Bulsara et al., 2014). The term women entrepreneurship means small business enterprises owned by women to reduce unemployment in any country (Jackson, 2015). The act of women owning small to medium-sized enterprises assists many families to be contributors to their families and their countries (Nandy & Kumar, 2014). Women living in remote areas can be economic contributors and be motivated to become leaders in the business environment through the acquisition of ICT skills. This study focuses on the Internet-enabled ICT centers located in the Western Cape and one telecenter in Johannesburg in the Gauteng province of South Africa. The locations used for the study were chosen due to the high unemployment rate in existence in these communities. These provide many free technological benefits such as the use of different ICT tools, assistance with employment application and skills development opportunities, free computer skills training and certification. Also, the Internet-enabled ICT centers provide ICT skills that are essential tools for entrepreneurship development, using work-integrated learning (WIL) techniques to teach women ways to improve their employability and personal development.

1.2 Entrepreneurship Strategies

Work-integrated learning (WIL) is a strategy to introduce educational activities and academic learning of a discipline with practical application into the workplace (Jackson, 2015). The purpose is to prepare and develop workplace requirements with learning-based skills, using a combination of both teaching and work-related activities during the teaching sessions to prepare learners for work possibilities (Jackson, 2015). This strategy is a suitable method implemented within the Internet-enabled ICT centers. The work-integrated techniques can be used to strengthen women's human capital in areas of knowledge, entrepreneurship management, skills development, employability, and personal matters at the grassroots level.

The Internet-enabled ICT centers consist of computers with Wi-Fi connectivity and other information technologies such as mobile telephone connections, fax, and printing machines (Gomez, 2014). Also, the Internet-enabled ICT centers are typically located in remote areas where private ownership of ICT equipment is relatively low. The purpose is to provide ICT infrastructure to communities in remote areas (Alao, 2019). These centers provide free computer training through work-integrated learning and preparatory support for the job market (Gomez, 2014). Also, the

Internet-enabled ICT center models are established in other countries and are known as public access points (PAPs) or Public-Private Partnership (PPP) telecenter models. These centers provide free services to the public since they are publicly funded (Gomez et al., 2012). Other telecenter names include information centers, Kiosks, e-Choppers, digital centers, public libraries, e-Centers, multimedia centers, computer centers, multi-purpose community centers (MPCCs), community technology centers (CTCs), and community access centers (Gomez et al., 2012).

Especially with the current technological advancements and technology adoption in small and medium-sized enterprises (SMEs), the establishment of small businesses in remote areas promises enhancement of women entrepreneurship for economic development and serves to promote gender equality by allowing for equal participation of all genders in the growth of any country (Brush & Cooper, 2012; Mathew, 2010). Therefore, women with digital knowledge can realize a productive business operation that can offer a competitive advantage, opportunities for participation in international businesses, technology transfer, collaborations, and development initiatives (Mathew, 2010). Also, access to technical skills is essential for acquiring information knowledge needed for economic development. This study aims to focus on using Internet-enabled ICT centers to improve women's entrepreneurship capabilities and employability in remote areas of South Africa.

The Internet-enabled ICT centers are used to introduce digital literacy in remote areas, especially while the current South African economy encounters an escalation in unemployment generally (Attwood et al., 2013). This technological initiative has the potential to completely redefine traditional gender roles, especially for women without digital skills, by providing an avenue for skills development and access to ICT resources toward improving women's digital knowledge (Haque & Quader, 2006). Therefore, this study poses the research question: How can Internet-enabled ICT centers promote women's technology inclusion for improved employability?

1.3 Research Rationale

Our study examines how Internet-enabled ICT centers can promote employability and entrepreneurship capabilities among women living in remote areas. Entrepreneurship is a component of business developmental ideas that are progressive for the economic buoyancy of any country (Bulsara et al., 2014). The essence of entrepreneurship is to develop various business opportunities for potential business owners (Bulsara et al., 2014). Women living in remote areas are facing more challenges to develop business skills compared to their male counterparts. Therefore, there is a need for these women to be given more opportunities to develop their small business ideas and professionalism (Bulsara et al., 2014). One step to meeting this goal would be to ensure that the women are technologically literate (Bulsara et al., 2014).

Entrepreneurship occurs from the perspective of when a person's creativity is realized in long-term business ownership, creating income and capital growth for economic buoyancy. Entrepreneurship plays a significant role in the socio-economic aspect of many countries, especially in addressing unemployment (Fazalbhoy, 2014). Women entrepreneurship is realized when women manage and organize all the aspects of production, as well as undertake risks and provide employment to others (Nandy & Kumar, 2014). Women from remote areas need to acquire digital skills that will prepare them for employment opportunities or assist them to establish small businesses in their communities for survival. Our study established that Internet-enabled ICT centers provide free digital skills training and many other assistances to unemployed women, using different information and communication technology (ICT) tools to achieve the possibility of being employed.

Women have limited business opportunities due to their lack of knowledge, mentorship, and adequate funds to support their entrepreneurial ideas. However, entrepreneurship skills through work-integrated learning programs using technology facilitate the delivery of skills needed to assist women to overcome unemployment (Alao, 2019). According to the South African Department of Trade and Industry, millions of Rands have been allocated to support female-owned small to medium-sized manufacturing enterprises (SMMEs) through government funding and grants, consultative support services and training.

However, a high rate of failed female-owned businesses exists (Irene, 2017). Thus, it is highly imperative to explore the relevance of technology to promote women's entrepreneurship capability for improved employability. This study, therefore, investigates how digital skills can improve women's employability, self-development, and entrepreneurship skills, thereby assisting them to operate their businesses more effectively and successfully.

2 Literature Review

2.1 Women's Perception of Technology

Studies by Hafkin and Huyer (2007) and Golmohammadi (2011) suggest that, without the development of conscious strategies, women are likely to be slower in adopting the use of technologies. The suggestions of these studies are for the development of women's inclusive initiatives and projects within society which could be effective measures towards motivating the interest and participation of women in acquiring technology-related skills.

Hafkin and Huyer (2007) emphasize the importance for women to understand their own information needs and to develop enough essential technical knowledge for the labor market. This study further states that women should be credible advocates of their views in policy debates on empowerment. This perspective serves to positively encourage female participation in society which is extremely necessary for reducing gender inequality.

Women's adoption of technology is generally perceived and linked to their subordination and unequal gender relations which are deeply rooted in religion, culture and historical laws, legal systems, political institutions, and societal attitudes

(Olatokun, 2008). This implies that socio-cultural values have strongly influenced the current state of access to and adoption of ICTs among the female population.

Moore (2019) states that a society's ability to develop depends on its capacity to access ICTs and establish this access as a basic human need and by inference, a basic human right. Based on establishing the intricate link between ICTs and women's rights, this study further emphasizes the need for women to integrate accessible technology into their lifestyles. This initiative could serve to include women in the use of skills for employability, entrepreneurship skills, and personal development processes while exploring and analyzing the extent to which these processes meet the needs of women with considerations of their perspectives.

2.2 Effects of Technology Adoption on Women Entrepreneurship Development

There is a growing concern about technology promoting gender inequalities which may potentially lead to social exclusion and contribute to a growing digital divide among genders (Asi & Williams, 2020). This study explores the extent of inequality and the inability of women to use technology for accessing information that can be used to improve their livelihood and self-development.

However, Internet-enabled ICT centers are technology enablers suitable to address gender inequality and women's ICT use (Alao et al., 2017). Alao (2019) further emphasizes the contribution of the ICT development projects toward improving digital skills among women through a study conducted on women living in remote communities of the Western Cape Province of South Africa.

In support, Gupta et al. (2019) state that technology could contribute to multiplier effects across income levels and innovative capacity. This study builds on the World Bank's (2012) views of expanding opportunities for economic development. It also discusses how ICTs can contribute to women's entrepreneurship skills development to specifically reduce poverty.

Many organizations have embarked on the sustainable development of women such as the Union for the Mediterranean (2016), an intergovernmental Euro-Mediterranean organization that comprises the European Union and 15 countries of the Southern and Eastern Mediterranean, women entrepreneurship is an essential tool for empowering women, growth, prosperity, and poverty reduction for a more equitable society. For this purpose, the Union for the Mediterranean (UfM) has embarked on sustainable and inclusive growth projects that have achieved the promotion of women's economic development by harnessing the potential of women entrepreneurs in many countries such as Algeria, Egypt, Jordan, Lebanon, Morocco, Palestine, and Tunisia.

The United Nations Industrial Development Organization (UNIDO) project supports women's entrepreneurship and promotes women empowerment for inclusive and sustainable development in the MENA region. The project was implemented by the Investment and Technology Unit (ITU), a subsidiary of the UNIDO Business, Investment and Technology (BIT) Branch. The project facilitated the following benefits for women:

- Provision of entrepreneurship development services to women and their networks through support dimensions for over 400 women business associations, banks, and business development services.
- Facilitation of over 2000 women entrepreneurs on entrepreneurship development and business plan formation.
- Enabling access to investment and finance to over 500 promising business opportunities.
- Contribution to the creation of over 800 new jobs upon completion of the project.

2.3 Technology Contribution to Women Employability

The Internet-enabled ICT centers or telecenters have proven to be reliable and acceptable technology models that can be used to promote the use of technology for business skills, employability skills, and enhance women's professional abilities to improve their personal and skills development. The use of technology tools in the Internet-enabled ICT centers promotes the economic empowerment of women by providing unemployed women from remote areas with digital skills for improved employability (Alao, 2019). The Union for the Mediterranean (UfM) projects executed similar initiatives in the Southern and Eastern Mediterranean region. These projects assisted disadvantaged, unemployed, educated, and non-educated women with essential skills such as English language training, computer and business skills, job search tools, and provide advice relevant to the job market.

Internet-enabled ICT center in South Africa has provided similar services such as free computer skills training to users in the country. These services assisted in improving employability to an extent, thereby improving digital literacy, and reducing poverty. These reported cases captured the perception of women as being inclusive and empowered. Nevertheless, certain conditions should be considered before women could benefit from using Internet-enabled ICT centers established in their communities. According to Woodard (2020), the following will need to be considered:

- Availability: Most Internet-enabled ICT centers are government-sponsored and consist of digital technologies (i.e., hardware or software) that are used to conduct computer skills training programs while accredited certificates are issued to registered users. However, it is important to ensure the availability of established Internet-enabled ICT centers that offer free services to women and girls for their personal development and improved employability.
- Access: Given that, except for mobile phones, unemployed women have limited access to technologies, it is important to ensure that digital technologies such as

computers, Wi-Fi access, fax machines, scanners, and smartphones are available and accessible to women users.
- Affordability: It is important to evaluate the affordability of the projected technology intervention for women users. This involves ensuring that the Internet-enabled ICT centers offer free services to users or establishing that the centers are government or non-government sustained.
- Ability: Given the level of education and literacy of most of the women who need to use the Internet-enabled ICT centers, it is crucial that the centers can offer digital skills such as traditional, numeracy, and digital literacy, as well as considerations of delivery of these training programs in the local dialect.
- Attitudes: The attitudes of women users about specific digital technologies may be of relevance to the desired outcomes. Thus, it is important to evaluate the societal beliefs that could hinder the use of technology by certain female user groups.
- Aspirations: It is critical to assess the aspirations of women users towards using technology and how this influences these users' economic participation in their respective domains. This involves assessing the reasons for the use and lack of use of ICTs by women in the workplace and homes for information to improve their economic standards, personal development, or social purposes. In the case of lack of use of ICTs, it is necessary to evaluate how technology intervention could help to put them on that path.
- Anticipated risks: It is imperative to assess the anticipated risks that may occur from using technologies. ICT centers need to offer services to users clear of any potential risks and to share them with the women users.

2.4 Factors Hindering Women from Using Technology

Economic empowerment is the development of the ability of the historically disadvantaged to engage in economic activities that benefit both the individuals and the broader society (Alao et al., 2021). Women face economic challenges that affect their employability status and there is also a high rate of unemployment among women caused by gender-based discrimination in many developing countries. Women are not economically empowered due to some factors caused by lack of employment opportunities, lack of education, and socio-cultural perceptions that are obstacles to their economic capability (Alao et al., 2017).

Despite the increased urban migration rate, fewer women than men migrate to urban locations in search of economic opportunities and a better lifestyle (Isabirye & Mamba, 2015). Traditional notions portray how women are perceived in society and affect their ability to have improved employability. These sometimes contribute to the factors that hinder women from being economic contributors in their respective domains (Stromquist, 2015). Women are sometimes prohibited from progressing beyond their traditional roles of home management which does not allow them to reach their full potential as individuals in society (Alao et al., 2021; Stromquist, 2015). Women are hindered from contributing economically which indirectly inhibits the positive effects on the often-struggling economies of developing countries (Stromquist, 2015).

Women continue to undergo a gender divide that prevents enhancing their personal development, especially instances when utilizing technology for informal learning for personal development and self-directing in the workplace (Abadi et al., 2020). Hence, the gender digital divide is one of the most significant inequalities amplified by the digital revolution (Moolman et al., 2007). Women continue to face gender-related discrimination that prevents them from accessing the full benefits of accessing digital skills and other skilled work which can be used to empower them economically (Hilbert, 2011). They are more likely to be unemployed and have limited employment and educational opportunities (Chadwick et al., 2013).

An increased number of these women, approximately 60%, according to Charmes (2012), end up as unpaid family workers. This is because women are usually trapped in traditional family roles and lack literacy skills that can allow them to achieve more of their potential (Antonio & Tuffley, 2014). Women are sometimes hindered from public spheres due to socio-cultural norms, lack of education and valuable digital skills. These barriers at times apply to both genders, but women usually face these obstacles more than men do (Moolman et al., 2007). Despite the challenges women face, they can be economic contributors in their countries. The next sub-section highlights the economic contributions of women.

2.5 The Implementation of Sustainable Development Goals for Women Development

The 2030 Agenda for Sustainable Development (SDG) identifies that the introduction of ICTs and global interconnectedness will have a great potential to increase human progress to bridge the digital divide, develop knowledge societies, as well as scientific and technological innovation (Graf, 2020; Tjoa & Tjoa, 2016). The implementation of SDG Goal 9, namely achieving industry, innovation, and infrastructure by targeting universal and affordable access to ICTs, and goal five, which is to achieve gender equality and realize women's human rights, establish the intricate link between the implementation of women development and the adoption of ICTs (Graf, 2020; Tjoa & Tjoa, 2016). ICT-based empowering solutions for implanting these SDG goals show that access to technologies has grown at a significantly fast pace that enables growth in business operations and education as well as enhances gender equality (Rosche, 2016).

The United Nations Millennium Development Goals (MDGs) claimed the effects of female empowerment on economic development is by "putting resources into poor women's hands while promoting gender equality in the household and society results in large development payoffs" (Doepke & Tertilt, 2019, p. 310).

The recognition of gender equality and the empowerment of women are significant goals towards achieving poverty reduction and the SDGs. These are otherwise recognized as the "Global Goals" and are widespread calls to accomplish an end to poverty, to protect the planet, and to ensure that all people enjoy peace and prosperity (Sachs, 2015).

Women remain significant supporters of their families and the society to which they belong. Hence, the empowerment of women can enhance development and increase opportunities and economic development (World Bank, 2012). Women in any country are economic contributors when they have been empowered. Therefore, there is a strong positive correlation between the relative position of women in society and the level of economic development (Doepke et al., 2012; Duflo, 2012). The empowerment of women as economic contributors will be a worthy achievement that will promote economic growth. The following sections highlight the framework used for the empirical study.

3 Framework: Individual Difference Theory

The Individual Difference Theory explains the difference in individuals due to environmental influences on personality and social behavior by specifying how these outcomes are affected by the individual experiences of people. The notion that individual differences cause differences in human behavior is not alien to research (Trauth & Quesenberry, 2007). This theory was applied in consideration of the sociocultural factors that helped to explain the participation of other under-represented groups such as women (Trauth & Howcroft, 2006).

The theory used individual differences to explore the factors that hinder the women living in remote areas from using the Internet-enabled ICT centers. Many women in these areas are not empowered or encouraged to have careers or develop entrepreneurial skills; however, they are expected to have a personal desire to manage their homes. These women are mostly hindered by socio-cultural norms, societal perceptions as well as economic factors, and beliefs practiced by society. Also, many women in these disadvantaged areas undergo more gender discrimination than women living in the urban areas of developing countries (Alao et al., 2017). Hence, this study focuses on the societal and economic factors that possibly hinder women living in remote areas from using ICT tools to attain entrepreneurship skills and improved employability.

The implications of using the Individual Difference Theory were to support and evaluate societal interventions directed at redressing individuals in society. This theory explains the various constructs that influence and hinder the participation of women using the Internet-enabled ICT center in remote areas. The Individual Difference Theory was grouped into three main constructs, as adapted by Trauth and Quesenberry (2005), as follows:

- Personal data: This concept includes the demographics of women such as age, ethnicity, and race. Other demographic data include the lifestyle that describes a person's life, past and present, in the socio-economic class and the individual's growing-up history, employment status, and lastly, parent and mentor type. Demographic data also include workplace data which contain information about a person's status (Trauth et al., 2004). The descriptive data of this study is related to women's individual differences of prior familiarity with or exposure to technology. The personal data explain women's experiences that hinder or influence their use of Internet-enabled ICT centers. In the study, the personal data of women using and not using the Internet-enabled ICT centers were presented and analyzed by, for example, age, education, and economic status.
- Shaping and influencing factors: This theory concept describes the factors that influence a person's decision to use ICTs, i.e. Internet-enabled computers to seek employment opportunities, small-medium enterprise ideas, or other personal development activities. This includes the person's characteristics such as educational background and personality traits as well as his or her need to use ICTs for work purposes or personal development. Other factors include personal influencers who motivated a person to use technologies, i.e. mentors, role models, and other significant others. Also, significant life experiences may hinder a person's ability to use digital tools, i.e. parents' lack of work or the early death of loved ones. The theory combines a person's characteristics, influences, and past experiences such as educational background, personality traits, interests, and the ability to attain relevant skills development. Also, the gender identity and behaviors associated with being female. For example, women users are encouraged to use the Internet-enabled ICT centers for personal empowerment.
- Environmental context: The theory concept explains the environmental context to include a person's cultural attitudes and values. These refer to the attitudes that motivate women to use the Internet-enabled ICT centers while other factors include economic and policy data, namely more of the sociocultural context that may obstruct women from using ICTs such as the societal or economic hindrance to using technology. The geographic data or the location of work explained the contextual information about the geographic region or location in which a person lives, i.e. an urban or remote rural location.

Collectively, these constructs contribute to the differences in individual behaviors and depict how personal experiences and the environmental influence of personalities affect an individual's life choices; for instance, the choice of a woman living in remote areas to access or use a computer can be hindered by various factors such as societal or economic status. Trauth et al. (2004) state that the theory views women as individuals who possess different technical talents and inclinations, and who respond to the social shaping of gender in unique and particular ways. This theory acknowledges that common social shaping messages are conveyed into subgroups in culture; for example, a woman's age, race, and ethnicity. At the same time, it also takes into account the varied influences of individual backgrounds and critical life events that result in a woman's response to certain situations. She may have the ability to use

ICTs for improved employability or personal development; however, not all women of a certain age group respond in the same way to commonly received messages.

Women are presumed not to relate well with technology and cannot use ICTs due to their individual life experiences that may have influenced their perception of technology use (Alao, 2019). Many women experience barriers that hinder their use of ICTs such as lack of ICT infrastructure, resources, and ICT skills together with software and hardware applications that do not reflect their female interests and needs (Best & Maier, 2007; Hilbert, 2011). There is a perception that ICTs can be empowering to some women, while other women are not feeling empowered. The Individual Difference Theory states the understanding of individual responses to common societal influences can be obtained from an understanding of the combination of personal characteristics and environmental influences; hence, the focus on differences within rather than between genders (Trauth et al., 2004). The individual differences in women's use of Internet-enabled ICT centers are presented in the study (see Table 1).

3.1 Rationale for Using the Individual Difference Theory

The rationale for using the Individual Difference Theory is that traditional gender roles have been evolving in recent societies and women are considered as economic contributors to the countries in which they live (Hassan et al., 2020). More women are taking on the role of managing the home and at times being the sole providers of their families. Despite this, women are still under-represented in the workplace and generally more limited in the employment aspect than men who are presumed to be the sole providers of the family. Men can seek jobs more easily than women who are mainly expected to manage their homes (Kabeer & Natali, 2013). This is due to the perception that women are assumed to be "caretakers" whereas male roles are perceived to be those of "breadwinners." Men are known to occupy a privileged position in society while women occupy a subordinate position in the same society (Ridgeway & Correll, 2004).

3.2 Conceptual Model

The study developed a conceptual model to explain how the Internet-enabled ICT centers can be utilized to improve women's employability and entrepreneurship skills development (see Fig. 1).

Table 1 Individual differences in women's use of the telecenters

Individual difference concept	Details of individual differences	Outcomes of individual differences in women's use of the ICT centers
Personal Data	Gender	Female respondents benefited from using the telecenters.
	Age	Age was not a contributing factor that hindered the use of the telecenters. Women of all ages used the telecenter services.
	Socio-economic factors	The socio-economic factors of women contributed to the high rate of unemployment in remote communities. Only a few women living in remote areas were employed or worked on the farm.
	Computer skills training	Computer skills training offered at the telecenters empowered women to become digitally literate.
	Race and ethnicity	The respondents of the study were mostly Afrikaans-speaking women from the Western Cape in South Africa.
	Parenting status	Most of the women were either single mothers, married, single ladies, or underage matriculants.
	Education	The lack of education hindered women's use of the telecenters.
Shaping and influencing factors	Role model	Women with prior computer experience, role models, mentors, workplaces, and college or school computer labs had a better chance using the telecenters.
	Personality types	Women's personality determined the telecenter usage.
Environmental context	Contextual factors	Contextual factors such as lack of availability of space, the insufficient timeframe of 45 minutes to use computers, and other societal perceptions of the telecenters hindered usage.
	Cultural norms	Cultural norms and beliefs were factors that contributed to the lack of telecenter usage.
	Location	The location of the telecenter hindered usage due to the distance and lack of awareness thereof.

4 Study Location/Setting

The location of the study was the Western Cape Province of South Africa. The province is the third most populated and fourth-largest of the nine provinces (Statistics SA, 2020b). The province is divided into one metropolitan municipality and five district municipalities that are divided into 24 local municipalities. The province consists of an estimated population of 7,113,776 of which 67% fall in the age group 15–64 years. The population in this age group is made up of 51.5% female and 48.5% male residents (Statistics SA, 2020b). The province contributes 14.21% of the national GDP which is the second-largest contributor to the total South African GDP (Statistics SA, 2017).

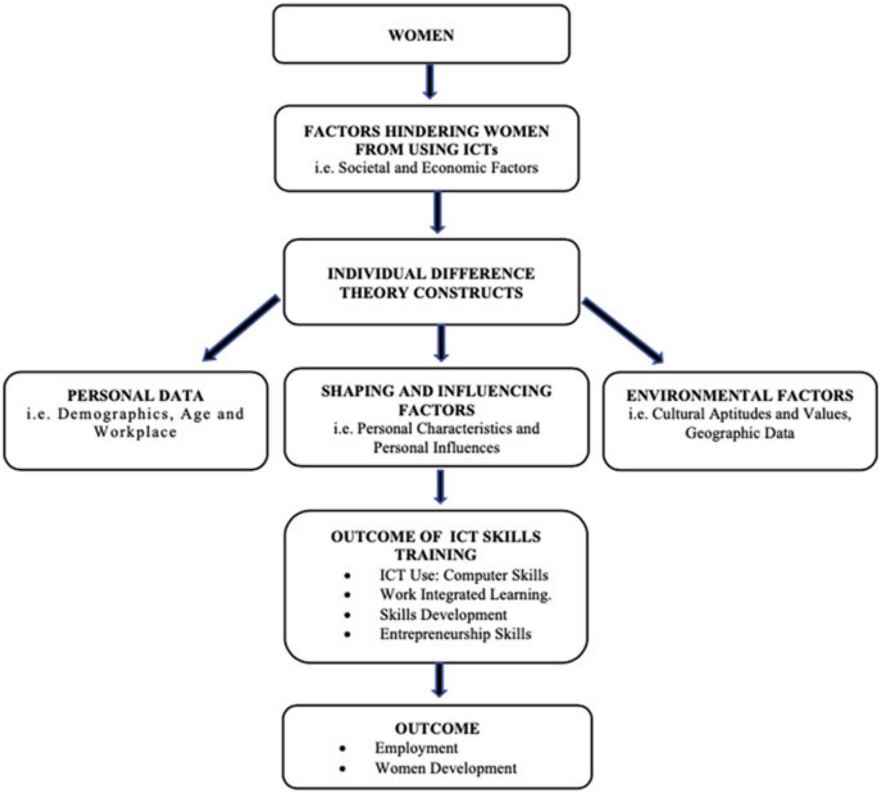

Fig. 1 Conceptual model for ICTs for women skills development

The province has a high unemployment rate and consists of 1.3 million residents who are not economically active, with 25% (552,733) unemployed and 122,753 residents who are discouraged work seekers (Ganie, 2016). Also, there is a 52% working-age population in the province compared to the 40% national average of the working-age population in the other provinces (Statistics SA, 2017). The population of the Western Cape consists of 50% Colored, 33% black African, 17% white, and 1% Indian or Asian (Statistics SA, 2017). In terms of language, 58% are Afrikaans-speaking, 24.7% IsiXhosa-speaking, 20.2% English-speaking, and 2.2% speak other languages (Statistics SA, 2020b). The median age of the female population in the province is 28 years and for every 100 women, there are 96 men (Lehohla, 2012) while 34% of households own a computer and 44% have access to the Internet to carry out various activities (Lehohla, 2012). Table 2 summarizes the key Western Cape statistics.

Table 2 Statistics of Western Cape Province (adapted from Statistics SA, 2020b)

Index	Western Cape	National
Population	7 million	57.4 million
Population group		
Colored	50%	80.7%
Black African	33%	8.8%
White	17%	8.1%
Indian or Asian	1.0%	2.5%
Other 93,969	1.61%	100.0%
Language		
Afrikaans	58%	13.5%
IsiXhosa	24.7%	16.0%
English	20.2%	9.6%
Other	2.2%	1.6%
Unemployment	25%	26.7%
Gross domestic product	14.21%	7.9%
Area (km^2)	129,449	1,219,090 km^2

4.1 The Cape Access Project

The Cape Access Project is a Western Cape provincial project that employs and trains people to become telecenter operators to manage the functionality and services provided to people using the telecenters (Alao et al., 2017). The objective of the project is to provide digital literacy to people living in remote areas of the province and to provide better quality ICT availability, access to education, employment, and business opportunities as well as increased socio-economic development in these areas (Alao, 2019). The Cape Access Project is operated in collaboration with community structures known as e-Community Forums. The project has provided more than 54 Internet-enabled ICT centers or telecenters to six districts and provided 10–12 computers with access to the Internet to all centers established in these communities (Alao, 2019). The services provided include free access to computer terminals and all ICT infrastructure such as lamination machines, photocopy machines, printers, and scanners. Other services provided at the Internet-enabled ICT centers include access to job databases, free personal e-mail addresses, government tender information, government funding applications, and various ICT services (Alao, 2019).

To achieve the objective of the initiative, computer skills training was provided to registered members for the international computer driving licence (ICDL) and the basic computer skills and e-Learner entry-level Accredited Certificate for successful learners. Thereafter, certificates are issued to participants (Alao, 2019). Apart from the range of ICT facilitates such as access to computers, the Internet, and cell phones, applications associated with these technologies are also available at established Internet-enabled ICT centers or telecenters to users for various purposes. These include employment applications, community projects, Internet banking, South African Revenue Services' electronic filing system (SARS e-Filing), CV creation, and digital skills training (Alao, 2019).

4.2 Programs of the Internet-enabled ICT Centers

The Internet-enabled ICT centers provide computer skills programs to users for Microsoft Office packages such as Word, Excel, PowerPoint, Access, Outlook, and Publisher as well as Internet connectivity and electronic mails. Other services entail the provision of information on employment and entrepreneurship opportunities, assistance with job applications together with assistance with the bookkeeping of small business records and managing of small business operations. Also, social media platforms such as Facebook, Instagram, and Twitter are among the program techniques that the Internet-enabled ICT center managers teach small business owners at the centers. These services are specifically aimed at social networking and business marketing which are essential in the digital era for women entrepreneurs to utilize to promote their businesses.

5 Design/Methodology/Approach

The Individual Difference Theory was used as a guide for this study analysis. The framework was used to explain how the different theoretical contexts were used to emphasize how women used technologies to improve their employability status, for their personal development, and for seeking information on different job opportunities or knowledge on different business ideas and other daily activities. The theory was used to address how ICTs could promote the digital inclusion of women as well as improve their entrepreneurship capability and employability prospects within and outside of remote areas that have a high unemployment rate. The study adopted a qualitative approach to understanding the empirical situation of the phenomena. The purpose was to present the views and perceptions of a total of 59 women who had participated in the data collection process. But only 39 women participated throughout the data gathering process in the Western Cape Province, while 20 of these women were from Johannesburg in the Gauteng Province. Therefore, only selected responses from 59 active participants were analyzed. A semi-structured in-depth interview was used to understand the insights of the participants on the use of ICT tools for employment, entrepreneurship, and personal development purposes. Furthermore, the semi-structured in-depth and focus group interviews were used to gather data to generate clear and precise responses to the research question posed.

The study focused on gender issues to address the stereotype of women not being contributors to economic development. The study considered suitable measures that could be adopted when diffusing new technologies in historically disadvantaged, remote rural locations (Antonio & Tuffley, 2014). Thus, the researchers conducted the study to investigate how women living in remote areas utilized the Internet-enabled ICT centers to seek employability opportunities, manage or operate their businesses, or carry out different daily activities. Finally, an explanatory approach was adopted in the study; thus, the research conducted was relatively explained

Table 3 Profile of participants (N = 59)

Age	User	Non-User	Absent Participants	Total
18–20	5	3	0	8
21–20	11	2	0	13
31–40	8	1	0	9
41–50	8	1	0	9
51-Above	6	5	9	20
Qualification				
Degree	1	0	0	1
Professional certificate	10	0	1	11
Matric	10	3	10	23
Grade 9 to 11	10	5	9	24
Location				
Elim	8	2	1	10
Laingsburg	3	0	18	3
Citrusdal	3	0	1	3
Klawer	9	3	0	12
Mbekweni	8	3	0	11
Tembisa	10	10	0	20
Employed	9	0	10	19
Unemployed	16	14	10	40

rather than simply describing the phenomenon. The participant's profile is presented in the study (see Table 3).

5.1 Population Sample

Purposive sampling was used as the sampling technique to select a target population of women who lived in remote areas at close distances to the respective Internet-enabled ICT centers. Internet-enabled ICT centers or telecenters, established by the Cape Access Project, were utilized to conduct a homogeneous study of telecenters with similar services for assisting people residing in remote areas to access ICT tools to tackle unemployment and poverty within these communities. The participants in the study were categorized into users and non-users of the ICT centers. The participants were between the ages of 18 and above living in the Western Cape Province and Gauteng Province of South Africa. Five selected remote areas, Klawer, Elim, Mbekweni, Laingsburg, and Citrusdal from the Wester Capeand-one Telecentre from Tembisa were selected for the study. Tembisa telecenter located in Tembisa Township in Ekurhuleni municipality was selected for the study because similar services offered in the Western Cape telecenters were offered to community users of this centre. Also, the Township has a high unemployment rate. The Tembisa telecenter offers accredited computer skills training to community members, internet

Table 4 Summary of the telecenter locations, municipalities, language preferences, population, and services

Telecenter locations	Municipality	Services
Elim	Overberg	Free computer training to community members on how to use computers; entrepreneurship skills development; certifications; assist with online searches, Internet banking, online chats, researching study opportunities, and registration for online studies
Klawer	West Coast	Free computer training services to all community members on how to use computers; entrepreneurship skills development; certifications; assist learners with school assignments, online job searches, and applications as well as access to government services and information
Mbekweni	Cape Winelands	ICT services to community members; access to government information and services; accredited computer skills training; certification and research information
Citrusdal	Cederberg	ICT services and computer skills training; entrepreneurship skills development; certifications; assist with the setting-up of e-mail accounts, online job searches, and applications
Laingsburg	Central Karoo District	ICT services and computer skills training; entrepreneurship skills development; computer accredited certifications; access to government information, services, job opportunities, business, and research information

Source: www.westerncape.gov.za/capeaccess/e-Centre

usage, provides accredited certifications, business, research and various information on various opportunities. The summary of the Western Cape Internet-enabled ICT center locations, municipality, language preference, population, and services is presented in the study (see Table 4).

Further, insights of women using and not using the Internet-enabled ICT centers were studied, and the perceptions and reasoning structures of the 59 women were examined. Many of the participants involved in the study were living in communities with a high unemployment rate and a small number of women who worked as seasonal farmworkers, casual workers, and entrepreneurs. A total of 42 participants (71%) were constant users of the digital center for various daily activities and only 17 participants (29%) were non-users of the services provided at the digital center. The criteria for the selection of Internet-enabled ICT centers used for the study were as follows:

- The telecenter should be situated in remote areas.
- The telecenter should have been in operation for more than one year.
- The telecenter should offer various free ICT services and opportunities for improved employability.

Table 5 Community telecenters plus dates and methods of data collection

Community ICT Center	Date
Mbekweni, Paarl	15 July 2014
Klawer	25 July 2014
Elim	2 August 2014
Laingsburg	19–23 October 2015
Citrusdal	26–30 November 2015

5.2 Data Collection

The participants used for the study were women between 18 and 60 years of age living in remote areas. Frequent users of the Internet-enabled ICT centers utilized the free services offered to search for employment opportunities, to operate their small business enterprises (SMEs), and for personal development activities. The non-users were women who did not use the Internet-enabled ICT centers due to a lack of interest to use ICTs, a lack of computer skills, and a lack of confidence to visit the ICT centers. Many women not using the ICT centers did not have the opportunity to use the services such as free computer skills training and entrepreneurship skills development offered at the centers.

Data for the study was collected using semi-structured in-depth interviews and focus group discussions. The participants gave feedback about how ICTs had improved women's employability and the factors that hindered women's use of ICT facilities. A five day data collection process was conducted for the Tembisa telecenter on the 20–25 July 2020 as a pilot study to compare similarities of the services offered to users in both telecenter locations. The summary of the Western Cape Internet-enabled ICT centers as well as the dates and methods of data collection are presented in the study (see Table 5).

5.3 Data Analysis

All interviews were audio-recorded and transcribed. We used thematic analysis to analyze the data collected using the six steps adapted by Braun and Clarke (2006). The computer-assisted qualitative data analysis software (NVivo v11) was used to analyze the qualitative data (Braun & Clarke, 2006). The data collected were coded and collated in an extensive list and the different codes were identified across the data set. The code created assisted in developing the categories into themes, followed by selective coding, and incorporating them into groups (Braun & Clarke, 2006). This phase re-focused on the analysis at the comprehensive level of themes rather than codes, involved sorting the different codes into potential themes and collating all the relevant coded data extracts within the identified themes (Braun & Clarke, 2006). The six steps of the thematic analysis phase, as presented by Braun and Clarke (2006), are shown in the study as follows:

5.3.1 Step 1: Familiarizing Oneself with One's Data

The researchers familiarized themselves with the data gathered. Thereafter they transcribed the data (where necessary) and read the data to jot down initial ideas to gain a holistic understanding of the data (see Table 6).

5.3.2 Step 2: Generating Initial Codes

Interesting features of the data were coded systematically across the entire dataset and the relevant data were collated into each code. The researchers first thoroughly read all the transcripts to understand the participants' responses with the study objectives. Thereafter, the researchers transcribed the interviews and coded the data (see Table 7).

5.3.3 Step 3: Searching for Themes

Codes were collated into potential themes and all data relevant to each potential theme were gathered. The researchers studied the transcriptions to identify themes which were then discussed with other researchers in a similar field of study for further feedback (see Table 8).

5.3.4 Step 4: Reviewing Themes

The researchers checked if the themes worked with the coded extracts (Level 1) and the entire dataset (Level 2), generating a thematic "map" of the analysis (see Table 9).

5.3.5 Step 5: Defining and Naming Themes

The researchers conducted ongoing analyses to refine the themes and the overall story to generate a clear definition and names for each theme. The researchers identified themes in all transcripts. They then repeated Step 3 carefully to clarify the categories and sub-categories by looking at their interconnectedness. The categories were generated from the transcripts (see Table 10).

5.3.6 Step 6: Producing the Report

The final opportunity for analysis allowed the researchers to select a clear and compelling extract, for example, the final analysis of selected extracts that relate

Table 6 Code presentation using NVivo (v11)

Construct	Interview Transcript
Attitudes/values of using the ICT center	"Normally there are ICT skills training programs organised for the community users, these programs are not specifically for women. Programs introduced to the people can never be enough especially when it comes to women empowerment and women entrepreneurship programs" [User-L3].
Demographics	"I am a known farmer; I work for myself with my husband and two sons. I also own an accommodation business and a fashion business, which I operate. From my business, I come to the ICT centre to use emails, to do online research, promote myself at the telecentre, to make copies and use Skype" [User-E7].
Personal characteristics	"I also use the e-Centre for my personal needs like social media" [User-C6].

Table 7 Codes created using NVivo (v11)

Construct	Initial code	Transcribed interviews
Access to job information	Use of ICT tools	"The users were shown on the website local, national and provincial government information, especially matriculants, I show them what they can do with their lives & that they should not say, they do not have money but search for possibilities on the Internet" [Telecenter manager-C1].
Access to ICT facility	Internet	"I use the internet at the ICT centre to search for jobs and to type and get some information" [User-M7].

Table 8 Description of themes created from codes

Theme	Description	Sub-Description	Respondents' View and Identification
How do telecenters contribute to women's entrepreneurship skills?	The contribution of telecenters to women's entrepreneurship skills	Impact	"In the past, people only had hand-written CVs and there was lack of communications as well, but now people are using the telecentre for communications, typing their CVs and accessing information for business opportunities because the services are free of charge in the ICT centre" [User-C15].
What factors hinder the use of the Internet computer center?	Socio-cultural factors hinder women's participation in the computer skills training	Factors affecting use	"The time is not right for women to come here because they are housewives" [Focus group Non-user-K4].

Table 9 Reviewed themes created from codes

Reviewed theme	Theme	Description	Sub-description	Respondents' view and identification
Attitudes/values to use ICT	How do women's attitudes/values motivate their ability to use the telecenters?	The motivation to use ICT centers for women's development	Impact	"In the past, people were using their hands to write CVs and there was lack of communications, but now people are using the ICT centre for communications, accessing information for their business because the services are free of charge at the digital hub" [User-C15].
Hindrance to use	How do socio-cultural factors hinder women's use of the ICT centers?	The societal perception depicts women should be housewives	Factors hindering the use of ICTs	"The time is not right for women to come here because they are housewives" [Focus group Non-user-K4]. "The challenge that people using the telecentre face is the issue of language and literacy. Many people want to learn to use the computer in their local language and not English" [Non-user-T1].

the analysis to the research question and literature to produce a scholarly report of the analysis. The researchers finalized the themes, categories, and sub-categories that emerged, and assembled the data under explicit themes, categories, and sub-categories. In the process, consistency was checked—in most cases through an assessment to see if there was consistency in and interconnections of data in each theme. Thereafter, they compared the themes, categories, and sub-categories with the transcripts to check for data that had been omitted. Thereafter they checked for coding consistency. Coding was then revised in a cyclic iterative process until sufficient consistency was achieved (Miles & Huberman, 1994) (see Table 11).

6 Findings/Result Interpretation

The findings from the study showed how women utilized the Internet-enabled ICT centers for their personal development, how they applied for employment opportunities and operated their small business enterprises (SMEs). Access to the free services offered at the telecenters provided users with the opportunity to reduce the cost of managing their small business operations because many women were

Table 10 Themes developed from codes

Theme	Description	Sub-description
Individual Difference Theory	The theory explains the differences in individuals due to environmental influences on personality and social behavior by specifying some of how these outcomes are affected by the individual experiences of people.	Expression of ICT use
Personal data	This includes the demographics of a person, i.e., age, ethnicity, and race as well as other demographic data such as the lifestyle that describes a person's life, past and present in the socio-economic class, and the individual's growing up history, employment and lastly, parent and mentor type.	Identity of ICT user
Shaping and influencing factors	This theory context describes the factors that influence a person's decisions to use ICTs to seek employment for improved livelihood and personal development. i.e., Women aim to improve their characteristics like educational backgrounds, personality traits, and capacity to use ICTs to seek work opportunities and personal development. Other factors include a person's influence like mentors, role models, and significant others that motived women's ICT capabilities.	Influence to use ICTs
Environmental context	The theory explains the environmental context to include a person's cultural attitudes and values, namely information on the geographic data or the location of work such as an urban or a remote location.	Value or attitude that motivates the use of ICT tools

Table 11 Codes created using NVivo (v11) (Braun & Clarke, 2006)

Construct	Interview transcript
Benefits of using the telecenters for women entrepreneurship skills development.	"Yes, the women who used the telecentre save money because the services are free. If they go to the library, they must pay for some services offered" [Focus group User-M2].
How the telecenters are used for business operations.	"Women benefit a lot from the use of the e-Centre. in my growing business as a commercial farmer, I benefit from the free services offered at the e-Centre like other organisations that also make free copies. People from shops, also come here to use the internet for 45 minutes free of charge. They do not have to pay for copies" [User-E6].
Use of the telecenters for personal development.	"I also use telecentre for my personal needs like social media" [User-C6].

allowed to use the ICT facilities for different purposes. This study investigated how technologies promoted women's entrepreneurship capability for improved employability in remote areas. Despite the factors that hindered some women from utilizing the Internet-enabled ICT centers, many other women visited the Internet-enabled

ICT centers to access information on possible business ideas and other various opportunities to improve their livelihood.

6.1 Benefits Women Users Derive from Utilizing the Internet-enabled ICT Centers

According to Nandy and Kumar (2014), many countries globally have supported the development of women entrepreneurship to enhance the advancement of economically stagnant countries in establishing technological social networks for an entrepreneurial culture that promotes small business enterprises. This research explores how technologies can improve women's employability, entrepreneurship skills, and personal development through the use of Internet-enabled ICT centers. Many women have registered online for distant-learning educational part-time certificate programs, diploma, and degree programs along with other educational activities such as using the telecenters to complete assignments and receive study notes online. Also, many women saved money whenever they utilized the ICT facilities to access information about possible job opportunities. Overall, many women used the Internet-enabled ICT centers to register their businesses, conduct business transactions, apply for government funding, do research, look for educational opportunities, gain computer literacy, improve their livelihoods, provide enhanced capacity to produce and print local content for free despite not earning an income.

> "In the past, people were using their hands to write CVs, there was lack of communication as well but now people are using the e-Centre to communicate, accessing information and operate their business because the services were free of charge" [ICT Manager-C1].

Many women used the ICT centers to operate their small to medium-sized enterprises or businesses as a means to sustain their families. Also, the women living in remote areas used the services of the ICT centers for personal needs to communicate with their social networks as well as relatives within and outside their environment on employment opportunities.

> "Women come to the ICT centre to use social media like Facebook to discuss with loved ones, seek job opportunities, while some come to the ICT centre to mingle and make new friends" [Focus group-User E2].
>
> "I use the ICT centre for my personal needs like using the social media" [Focus group-User C1].

Similarly, many women used the ICT centers as social community networks to assist other users to apply for job opportunities.

> "I think the women use the telecentre for social networking because you don't see a lot of men using the internet for social media but only for businesses only. Also, it is the women that use it mostly for social media, not men (lol!)" [User-M1].

> "Yes, there is a woman whom we helped at the ICT centre to get a job, she is a chef and we helped with her CV, and she got a job at the children's school" [ICT center manager-K5].

> "Yes, . . .three women . . . were part of the computer skills training offered at the ICT centre and one got a contract job at Standard Bank. When the contract expired, she applied for another job and started working at another organization. Women also got jobs as client service manager in private organizations" [Focus group User-C6].

Many unemployed women visit the Internet-enabled ICT centers to access online information together with local, national, and government websites to seek and apply for entrepreneurship opportunities and job prospects to overcome their unemployed situation and enhance their circumstances.

> "The users of the telecentre were shown opportunities on the website of local, national, and provincial government information. Especially the high school matriculants are shown opportunities about what they can do with their lives because these young people do not have money so they always search for possibilities on the internet" [Focus group-User C3].

> "I have my own business of curtain sewing. I am an entrepreneur that always visits the ICT centre to get unique designs for my business. This business helps me sustain my family" [Focus group-User K3].

In addition, many unemployed women use the ICT centers to seek employment possibilities like contracts and permanent and temporary job opportunities while other women use the telecenters to interact with women assistance forums that offer skills development programs like non-government organizations (NGOs) about their prospective entrepreneurship ideas.

6.2 Factors Hindering Women Non-Users from Utilizing the ICT Centers

The framework of the study dwells on the individual differences among people that either hinder or impact the use of ICT tools (Trauth et al., 2004). The framework provides in-depth information on the lifestyle and socio-cultural factors that hinder women's ability to utilize ICT tools to attain entrepreneurship skills, seek employability and improve their personal development. Many women face societal and economic challenges that hinder them from utilizing ICT tools. These entail domestic violence, socio-cultural status, and high rates of unemployment (Hilbert, 2011). Due to these challenges, many of these women have to work on community farms as seasonal harvesters of fruits with their children to generate little income.

> "Most women in Klawer are unemployed. They don't have jobs and some of them are single mothers with no jobs. Only the women try to look for how to feed their children because the men in Klawer expect the women to go and look for jobs because of sociocultural perspectives. This is because on Friday evenings the men want women to provide money for them to drink, and when they don't give their husband the money, they are beaten up and there is domestic violence" [Focus group Non-user-K3].

> "Women say only men can use the ICT centre" [Focus group Non-user M8].

> "The time is not right for women to come here because they are housewives" [Focus group Non-user-K4].

Studies have shown that women living in remote areas are not allowed to participate in community development projects (Alao et al., 2017; Hilbert, 2011). Apart from the individual differences of women using ICT tools for their personal development, many women are obstructed from having an opinion in community initiatives due to societal perceptions that women are primarily home caretakers and not economic contributors to society (Antonio & Tuffley, 2014).

> "It is hard for women in this community because the community council is not engaging with women in this community. Women are struggling with the council in our area because in Klawer initiatives that are focused on empowering women is not a lot" [User-E4].

Furthermore, many women were non-users of the Internet-enabled ICT centers due to socio-cultural perceptions that affected their interest to utilize the services offered at the telecenters. This was because of the societal perception that the ICT centers were a mainly male-dominated space to seek employment opportunities and not for female users.

> "The societal perception is that women are more of housewives and the men go to the telecentre to seek for jobs" [Non-user-M6].

> "Many of the women in this community were stranded because of their husbands' Many women have men, and because of the socio-cultural perception the men would say no to the women and they are not allowed to visit the telecentre because women are expected to respect the man who is the house" [Non-user-M7].

Although, some women visited the Internet-enabled ICT centers to utilize the services provided to frequent users to overcome difficult socio-cultural situations through self-reflection (critical concentration) of their cultural norms, many other women were assisted to conduct online research on possible opportunities that could enhance their personal development and employability. Other findings showed the gender-biased usage pattern that hindered women from utilizing the Internet-enabled ICT centers due to the negative societal perception of the centers being more ideal for male users than female users. Hence, this negative societal perception influenced the behavior of women non-users to not utilize ICT tools (Cheryan & Markus, 2020). However, the telecenter operators distributed pamphlets to create awareness of the usefulness to frequent users of the facility; i.e. community members with limited computer knowledge or interest, little time or full schedules to utilize the facility, and others who lacked knowledge of the services provided to users.

6.3 Personal Data of Participants

The age of the participants was not an obstruction to the women using the ICT centers because of their genuine interest to be computer literate and attain skills development (Trauth et al., 2004). Many women from different age groups gained computer skills, using the ICT centers to communicate with the outside world and to attain individual development which contributed to community development and advancement.

> "I think the telecentre aimed to empower people with computer skills, to give them online training and connect people to the outside world because this is a very small place. I must say the government did an excellent job. In the past, I was a part of this group that established the telecentre" [User-E2].

However, the personal data or the demographics of the women living in the remote areas were generally conclusive, as these communities had a high unemployment rate, poverty, lack of ICT skills or interest, and the ability to use ICTs in the selected communities. Moreover, many women were only used to a concurrent daily lifestyle before the advent of the Internet-enabled ICT centers in their towns.

6.4 *Shaping and Influencing Factors of Participants*

Many women that live in remote areas continue to face gender-related discrimination that prevents them from accessing the full benefits of becoming computer skilled (Hilbert, 2011). This is because many female non-users lack the interest to utilize the Internet-enabled ICT centers due to a lack of prior exposure to computers that could shape and influence their abilities to use technologies. According to users of the Tembisa telecenter in Johannesburg "The problem with people not using the telecentre is technophobia. Many people are not familiar with the complexity of using technology" [Non-user- T2]. While responses received from the Western Cape telecenter were stated as follows:

> "Maybe they are scared that someone may laugh at them and that they are not computer literate" [Focus group Non-user-M3].

> "Women in Klawer walk on the farms mostly, and otherwise we survive on social grants. There is drug abuse, prostitution, unemployment, a high rate of crime, dropouts. Mothers and fathers drink excessively, and this affects the children" [Focus group Non-user-M1].

Other contributing challenges that affect women's ability to utilize the Internet-enabled ICT centers to seek self-employment or entrepreneurship skills development opportunities include the lack of education, self-assurance, and self-confidence. These factors hinder many women non-users from visiting the Internet-enabled ICT centers to seek personal development opportunities.

> "Women lack education and are scared to use the computer to source for personal needs" [Focus group Non-user L4].

> "The lack of education and being afraid to come and sit here to learn from the computer skills training program. Many women lack confidence which is the reason they don't want to come here" [Focus group Non-user-E1].

Furthermore, some women non-users were not utilizing the ICT centers because of the lack of information capabilities, i.e. the lack of awareness of the existence of the centers and the benefits provided to frequent users of the Internet-enabled ICT centers for their personal development.

> "Women not using the ICT telecentre miss a lot. On the internet, you see a lot of things" [Focus group User-K13].

Hence, some women non-users were not beneficiaries of the Internet-enabled ICT centers and could not strengthen or improve their economic standards due to the lack of experience or familiarity with using technologies.

6.5 Environmental Context of Participants

A remote area is a geographic setting that is situated outside towns and cities with a sparse population (Maumbe & Okello, 2013). The geographic locations of the Internet-enabled ICT centers utilized for this study are all situated in remote areas. Many women residing in these areas undergo daily challenges that affect their ability to utilize these centers. Findings showed that the distance to the facility was not conducive for women to travel. Other challenges included the traditional perception that women were expected to manage their families and not seek careers while the men were responsible for seeking employment opportunities.

> "The location of the ICT centre is not good now because there is no branding, the ICT centre is hidden, and people don't know where the telecentre is situated" [Focus group User-C5].

> "Space is a barrier; lack of computer literacy and the location is not suitable. The telecentre is not close to the suburbs because most people from the suburb must walk a distance to visit the facility to use the free services. There is a lot that can be done using the telecentre but only if more space and more ICT centre can be created in the suburbs" [ICT center manager-L1].

> "The women are more of housewives and the men go seeing for jobs at the telecentre" [Non-user-M6].

The challenges women faced were structural and contextual. Some women claimed that the Internet-enabled ICT centers provided a limited 45 minutes time slot to users trying to complete a task using the computer daily. Also, the respondents claimed the ICT facilities consisted of very limited computers available to users.

> "The time is not enough, the ICT centre closes early. By the time, we come back from work the ICT facility is already closed" [User-C5].

> "There is not enough space and computers for people to use at the ICT centre. I will be glad if we can have more computers at the ICT facility, then the centre can accommodate more users" [Focus group User-C7].

On the other hand, many women were privileged to live within proximity of the Internet-enabled ICT centers and able to use the free ICT facility and services to improve their livelihood as well as carry out daily online tasks and conduct research about opportunities outside of their communities.

> "Yes, there is this woman whom we helped at the ICT centre to get a job, she is a chef and we helped her with her CV, and she got a job at the children's school. Another lady did a

> computer course, and she got an administrative job at the local clinic" [Telecenter manager K2].

Literacy is key to knowledge since, without literacy, there can be no self-development, particularly for women and girls (Dighe & Reddi, 2006; Sen, 1999). Findings show that many women have utilized the free services for business development and personal growth offered at the Internet-enabled ICT centers.

> "You can change your income by a second if you can search for a job online at the telecentre. Also, there is a lot of stuff you can do at no cost" [User E19].

In essence, findings from this study show that the establishment of the Internet-enabled ICT centers in remote areas has been of tremendous benefit to the lives of many women who live in these areas, especially as many of them value the presence of the ICT community development initiative in their communities.

7 Discussions

The research discusses the importance of technology in women's economic productivity (Hassan et al., 2020). The use of ICT is significant to the growth of the world economy, as technology can be used to promote privately owned businesses, organizations, and communities to tackle socio-economic challenges and provide greater opportunities for empowerment purposes (Hassan et al., 2020). Access to ICTs has been an important aspect of women's development, as it improves their knowledge of digital skills, information, employability, catalyzes to grow entrepreneurship and economic opportunities (Hassan et al., 2020).

Women's access to technologies for personal needs can be attained through the use of ICT centers (Alao et al., 2017). Women who know how to use technology usually have confidence, high self-esteem, feelings of self-efficacy, and control over their lives as well as increased critical awareness and civic participation (Alao, 2019; Mat Aji et al. 2010). Some women do not perceive the use of technology as a luxury but instead as a determinant of the sustainable development of individuals for improved employability (Alao et al., 2021). Therefore, technology is viewed as crucial in the development agenda because it can be used in public administration, business, education, health, and the environment, among others (Williams et al., 2020).

In some instances, women were successful in utilizing technology and became technology entrepreneurs through determination to own their businesses despite the misrepresentation of women in the workplace (Williams et al., 2020). Studies showed the misrepresentation of women in the IT sector (Trauth et al., 2004; Zikode, 2020), as women's participation in the digital era is limited (Zikode, 2020). Some studies explored trends in the employment of women in the IT sector (Mishra, 2019; Klugman et al., 2014) while others examined the interventions that attracted women's development and retained women in the ICT sector as a means of organizations gaining a competitive edge in the IT sector (Zikode, 2020). However, in countries like South Africa, Internet-enabled ICT centers are used as work-integrated learning centers to also provide women users with digital skills that can be used for improved employability (Alao et al., 2021).

Research from other countries shows that ICT applications have empowered women to promote their businesses, upsurge their level of proceeds, have enhanced access to information on employment opportunities, and support their economic empowerment (Alao, 2019; Potnis, 2015; Suresh, 2014). Projects like the SMILE project in India have increased the literacy levels of disadvantaged women using ICT tools like telecenters (Suresh, 2014). Likewise, in this study, small business owners such as women commercial farmers, and entrepreneurs used the digital centers to operate their businesses to establish a daily routine of Internet browsing, printing copies, and scanning and laminating documents at no charge.

In conclusion, the establishment of Internet-enabled ICT centers allows many women to have improved employability and to be included in the digital revolution. Hence, women who participate in the computer skills training program provided at the ICT facilities share their success stories of employment opportunities. Other incentives offered by the Internet-enabled ICT centers include ICT skills development, improved communication, access to information and employment opportunities, access to government information, and strengthening social capital.

8 Practical Implications

This study suggests to the government to consider identifying measures that promote women's entrepreneurship in remote areas. The government should focus on creating policies that support gender equality in the area of entrepreneurship to avoid the exclusion of women. Furthermore, the research suggests to the government and ICT policymakers to place more emphasis on policies that will promote women's ICT skills and technology inclusion for improved employability. Hence, the study encourages transformation in the gender use of ICTs to promote digital skills among women in the area of entrepreneurship.

This study focuses on using digital skills to promote the development of entrepreneurship skills that women with small business enterprises can use to successfully manage their businesses; thereby, applying the outcome of the study in the implementation of entrepreneurship culture. The study has novelty because it describes how technology is used to promote women's entrepreneurship for improved employability. The research makes practical contributions to the government and private sector to promote the use of technology to enhance women's digital and entrepreneurship capabilities for improved employability. The study makes significant contributions to the business management field and the current thinking because it provides insights into the evidence shown in the outcomes of women's technology use to enhance their entrepreneurship capability using the Individual Difference Theory.

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Key Terms and Definitions

BIT	Business, Investment and Technology Branch
ICTs	Information and Communication Technologies
ITU	Investment and Technology Unit
MDGs	Millennium Development Goals
SDGs	Sustainable Development Goals
SMEs	Small to Medium-Sized Enterprises
SMMEs	Small-Medium Manufacturing Enterprises
UfM	Union for the Mediterranean
UNIDO	United Nations Industrial Development Organization
WIL	Work-Integrated Learning

Appendix 1 Interview Guide (Part I)

Interview schedule questions for women users and non-users

Biographical Details

Name/pseudonym					
Age					
Marital status					
Number of children					
Nationality					
Race					
Languages					
Level of education	Less than matric		Matric	Certificate in the trade	Professional course
	Gr 1/8	Gr 9/11			
Employment/ occupation					

Section A: Awareness

1. How did you know about the telecenter?
2. In your view, what was the aim for establishing the telecenter?
3. Who are the target users for the telecenter?
4. What is your understanding of a telecenter?

Section B: Use of Telecenter in women's daily lives

5. How long have you been using the telecenter?
6. How have women incorporated the telecenter into their daily lives?

7. What do you use the telecenter for whenever you use it?
8. What benefits do you derive from using the telecenter?
9. What do you find attractive about the telecenter?
10. What challenges do you experience when using the telecenter?
11. What things do you do at the telecenter that you could have done in person elsewhere?
12. What prevents other people from using the telecenter?
13. If the government asked you if you needed a telecenter OR something else in this community, what would you prefer? Please explain why.
14. What do you think of the location of the telecenter?
15. Before the establishment of the telecenter, what were you using to access information?
16. How has the telecenter affected women in becoming empowered?

Section C: ICT proficiency

17. How and where did you learn how to use a computer?
18. What skills do you have relating to IT?
19. What computer programs do you know?
20. What do you use these programs for when you visit the telecenter?
21. Besides the telecenter, where else do you access computers?
22. What draws you to access computers at the other site?
23. What, do you think, other people, use the telecenter for when they visit it?

Section D: Mobile phone use

24. Do you have a cell phone?
25. What brand of cell phone do you have?
26. What are other people using their cell phones for when using them? If you had a more advanced cell phone, what would you want it to do?
27. If you have/had a mobile phone with Internet access, would you still visit the telecenter?
28. What challenges do you experience using your cell phone?

Section E: Empowerment

29. What challenges have you faced in your daily life as a woman in the community in the past?
30. What challenges do you currently face as a woman in this community?
31. What, do you think, ICTs can do to assist in dealing with those challenges?
32. What other values, do you think, women get from using the telecenter?
33. What, do you think, those who are not using telecenters are missing out on?

Section F: Benefits

34. What things do people do to use the telecenter which would have otherwise cost them money to do in person?

35. In your view, how does the use of the telecenter help in the following:
    (a) Saving money.
    (b) Making money.
    (c) Getting a job: How do you think women got jobs? In addition, for women that have not gotten a job yet, why do you think they have not gotten jobs yet?
    (d) Access to services and opportunities such as health, education, e-government services?
    (e) Improve the level of your skills: computer skills, information literacy, leadership skills.
    (f) Ability to express opinion and participation in setting the agenda for issues related to the welfare of the village.
    (g) Access to information and knowledge to help solve your problems/needs.
36. Would you tell me of any stories that you have heard about someone who benefited from using the telecenter?
37. Are there any risks or bad things that you think come from using the telecenter?
38. As a woman, what do you think about other women who use computers at the telecenter?

Section G: Design Phase of Telecenter

39. Before the telecenter was established, were the women in the community informed of this initiative by the government?
40. Are there programs that empower women during the computer skills training taking place at the telecenter?
41. Did women participate in the design phase of the telecenter?
42. Are there special programs for women during the computer skills training sessions at the telecenter?
43. What campaigns are held in the community promoting the use of the telecenter in the community?
44. Do you think the government considered women during the design phase of the telecenter in the community?
45. Have any awareness campaigns introduced the Internet-enabled computer as an ICT initiative that can be used for empowerment in the past?
46. Are there enough resources for the efficient running of the telecenter as follows?
    (a) Finance.
    (b) Manpower.
    (c) Infrastructure.
47. How has the telecenter assisted in empowering women in the community?

Section H: Telecenter linking the government and community people

48. Are the telecenter managers acting as the intermediary between the community people and the government? If yes, please explain how the telecenter managers have acted as the intermediary between the community people and the government?

Section I: Information on the Individual Difference of women

49. Do have any knowledge on how to use the computer?
    (a) If yes, how did you know how to use the computer?
    (b) If No, please explain.
50. Were you ever exposed to a mentor that taught you how to use the computer in the past?
51. Does your culture hinder you from using the telecenter?
52. Is the geographical location of the telecenter conducive for you to access the telecenter?
53. Are you employed or unemployed?
54. Do have any knowledge on how to use the computer?
    (a) If yes, how did you know how to use the computer?
    (b) If No, please explain.
55. Do you have an idea of how to use the computer? If yes, how do you use the computer?

    Conclusion: Are there any questions or anything you want to add?

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Independent Power Supply Through Off-Grid Microgrids in South Africa: Potentials of AI Enhanced Business Models

Robyn Blake-Rath, Anne Christin Dyck, Gerrit Schumann, and Nils Wenninghoff

Abstract Reliable, affordable, and sustainable electricity access is crucial for positive economic and social development. A large share of the population is, however, still not connected to the power grid. Moreover, the reliability cannot be ensured by the current electricity production and management within the South African power grid, resulting in outages. Furthermore, the current fossil fuel-based power generation, together with additionally installed backup diesel generators counteracts global climate change targets. This leads to a power grid transformation necessity, addressing the existing sustainability challenges. This paper therefore analyzes AI supported off-grid microgrids possibilities, using South Africa as a case study. For this purpose, technical and sustainable aspects of the current power grid status are analyzed. These issues are then addressed holistically, using current smart grids research results, together with AI enhanced forecasting technologies from the field of deep reinforcement learning, resulting in a feasible business model opportunity. The identified ICT opportunities have, however, the ability to contribute to a future, where the integration of renewable energies in interconnected, decentralized microgrids, together with preventing supply and consumption mismatches, provides the foundation for an affordable, reliable, and sustainable access to electricity for all.

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1 Introduction

To this day, South Africa's electricity supply faces different challenges from all pillars of sustainability. On the one hand, the predominantly coal-based electricity production makes a conversion to renewable energies difficult due to its long-standing and, above all, cost-effective implementation. While, on the other hand, the old and simultaneously poorly maintained power grid leads to recurring supply bottlenecks. When these bottlenecks reach a certain level, load shedding is applied to prevent a total national blackout (Eskom, 2020c). Another critical aspect to be considered is the poor supply of electricity in rural areas, which is primarily due to the fact that the efforts required to reach these areas are mostly uneconomical (Motjoadi et al., 2020).

One of the Sustainable Development Goals (SDG; goal 7) targets at ensuring the access to affordable, reliable, sustainable, and modern energy for everyone (United Nations, 2020). In regard to the South African power grids and its implications on sustainability, this goal is partly violated. The United Nations (2020) state in their latest SDG Report that the deficits in electricity are worldwide increasingly concentrated in Sub-Saharan Africa (SSA), affecting about 53% of the population. In addition to existing sustainability issues due to unavailable access to electricity and blackouts, the COVID-19 pandemic has further stressed the need for reliable and affordable electricity. Unscheduled outages, unelectrified health facilities, as well as damaged equipment due to poor connections and voltage fluctuations affected the health service capacity (United Nations, 2020). The desired sustainable energy transition towards reaching this goal requires improved energy efficiency and load management, reduced carbon dioxide emissions, and increased integration of renewable energy sources, which are likely to lead to changes in consumer behavior, market performance of energy/electricity markets, shifts in roles of market actors, and structural changes in the livelihoods of the people. In this context, great expectations are placed on an electricity system and market transformation, labeled as smart grid (Meadowcroft et al., 2018), in which the grid can be stabilized through a continuous two-way exchange of energy and information, as well as a use of advanced analyses and control mechanisms.

In addition to an increased usage of renewable energy, a smart grid is also expected to drive a transformation from centralized to decentralized power generation (Arritt & Dugan, 2011). Advances in technology—particularly ICT—have the potential to enhance the establishment of such a transformation. An elementary component of this transformation is the use of automation technologies, through which additional information can be generated and analyzed. In the context of smart grids, these technologies can be used to predict long- or short-term power consumption and generation or to control and (partially) automate power generation and load. The key strength of the ICT-enabled grids is therefore to address cross-dimensional challenges of sustainability. They can increase the inflow of electrical energy and support the efficient usage of the resource (Caputo et al., 2018). Regardless of the given technological potentials, the transformation to a fully decentralized smart grid is challenged by the conditions of the South African energy market. The latter is determined by the state monopoly or quasi-monopoly Eskom, which makes electricity trading an important component for a decentralized smart grid impossible (Kenny, 2015). However, one possibility to establish a smart grid in South Africa is the use of off-grid microgrids. As a sub-category of a microgrid —i.e., an independent, regional, or municipal energy system (Longe et al., 2017)—an off-grid microgrid operates completely independently from the national grid. That means, it does not feed into the grid or draw power from it. An important feature of microgrids is the intelligent distribution of the renewable-generated electricity. Since these energy sources do not typically yield power at a steady rate, a particular challenge lies in the precise prediction of the electricity production rate. Simultaneously, electricity demand must also be predicted and reconciled with given electricity generation. This task requires intelligent control and distribution solutions that should be investigated on both technical and economic levels.

For this purpose, this paper provides an overview of the sustainability challenges related to the current power grid situation in South Africa, as well as the technical options addressing the identified issues. Building on these findings, an overall view presenting method for accomplishing the forecasting and control tasks is given and, moreover, opportunities offered by an expanded business model for establishing off-grid microgrids in South Africa are highlighted.

Firstly, the current situation of the South African power grid together with related sustainability challenges is described in addition to introducing smart grids and their potential of solving the identified issues (Sect. 2). The technical approaches that can be used to predict electricity generation and consumption are then presented in Sect. 3. In the fourth chapter, the possibilities and potentials of deep reinforcement learning for grid control are discussed. Furthermore, the opportunities of an expanded business model for off-grid microgrids are presented (Sect. 5). The concluding Sect. 6 summarizes the key findings and in addition provides an outlook and further research opportunities.

2 Theoretical Background

In the following chapter, the current situation of the South African power grid and the resulting consequences regarding the three sustainability pillars will be presented. Technical solutions that have the potential to address these issues, such as smart grids, will then be additionally presented and discussed in terms of the South African context.

2.1 The South African Power Grid and Related Sustainability Challenges

According to the Ministry of Mineral Resources and Energy, the total power generation capacity in South Africa from all sources is approximately 58,095 megawatts (MW), with 48,380 MW from thermal, 3485 MW from hydro, 2323 MW from wind, 2323 MW from solar, and 580 MW from other sources (USAID, 2020). 95% of the total energy production is generated by the state-owned utility Eskom (Eskom, 2020a). The transmission grid is also owned by Eskom and is responsible for 60% of the electricity distribution. The remaining 40% is covered by the 257 municipalities (Baker & Phillips, 2019). With the exception of a few municipalities that also generate their own electricity, they buy the electricity from Eskom and distribute it within their jurisdiction. By selling electricity to Eskom or directly to a customer, this also allows small independent power producers (IPPs) to import electricity into the grid (Hansen, 2000). The transmission of electricity to the various load centers in the country is largely conducted via a 400 kV grid that extends over a length of 19,743 km. In addition, power lines with voltages of 765 kV, 533 kV, 275 kV, 220 kV, and 132 kV are used, covering another 13,284 km. Distribution is handled by a network of 351,023 km of overhead lines and 7734 km of underground cables—each with voltage ranges of 1 to 22 kV, 33 kV, 44 to 88 kV, as well as 132 kV and higher voltages. The underground cables are primarily in the 44 to 88 kV voltage range and the overhead lines in the 1 to 22 kV voltage range (Eskom, 2020b). The responsibility for distributing the electricity is shared between Eskom, the municipalities, and other licensed distributors (Buraimoh et al., 2020).

Since 2008, Eskom has faced the challenge of meeting the country's electricity demands in a holistic manner. For this reason, the company introduced load shedding, which is a method to avoid a total national blackout by rotating the outages. Essentially, the electricity load is reduced by interrupting supplies to certain areas in a systematic and controlled procedure. The goal is to balance and level out the flow of electricity to the millions of households and businesses throughout the country. Thus, load shedding is implemented as an expedient solution for short periods of time. It is executed in stages and depends on the extent of the shortage of electricity generation (Eskom, 2020c). One of the key reasons for the application of load shedding is the inconsistent electricity demand. During peak periods, demand is higher and the continuous growth in the number of customers requiring electricity services results in supply bottlenecks. Furthermore, Eskom faces the challenge of a constrained power system, in which the older power plants, together with the existing infrastructure, are operating at full capacity in order to meet the growing demand (Eskom, 2020c). Other reasons are seen in unscheduled maintenance, design flaws in the new Medupi and Kusile power plants, financial pressure and poor management (Buraimoh et al., 2020). In addition to the recurring grid overload and the resulting implementation of load shedding, there are also some areas in South Africa that are still completely without electricity supply. According to the

South African General Household Survey, only 85.0% of all South African households are subsequently connected to the electricity grid (GHS, 2019). Furthermore, South Africa was confronted with the energy crisis of 2007–2008 leading to enduring shortages in the following decades, due to inefficiencies in its electricity system, as well as its generic energy policies (Ateba & Jurgens Prinsloo, 2019).

The impact of households not being connected to electricity has been extensively researched, showing economic, ecological, and social effects in addition to health issues (Pereira et al., 2011; Bridge et al., 2016a). Major negative effects on the household's income, educational attainment, and agricultural productivity have been documented (Bridge et al., 2016a). Through electricity induced possibilities such as increased wealth, spread of information via technologies such as TVs, as well as improved health care services have the potential to improve the nutritional status of children (Fujii et al., 2018). In addition, human health, as well as the environment, is at risk due to unavailable access to clean cooking fuels or technologies. The population growth, especially in sub-Saharan Africa, has exceeded the growth of available access to clean cooking solutions leading to a continuing exposure of mainly women and children to the harmful household pollution arising from the current cooking situations between 2014 and 2018 (United Nations, 2020). Niu et al. (2013) show that long-run bidirectional causality exists between electricity consumption and five human development indicators. Countries with high incomes have therefore a greater electricity consumption resulting in higher levels of human development. Electricity can be seen as a representation of modern energy. The level of electricity consumption can therefore be seen as a criterion of a country's development level (Niu et al., 2013). Income explains, on the one hand, whether a household is connected to electricity, and on the other hand, household electricity connection has a major effect on the income (Bridge et al., 2016b).

Not only the absence of access to electricity but also the occurring electricity outages in the form of blackouts have multiple implications on sustainability. These outages tend to concentrate on poorer regions within countries, due to economic and political factors (Aidoo & Briggs, 2019). Unreliable electricity supply not only affects households but also business and as a result the overall economy. To avoid losses (e.g., spoiled goods and business interruption) during power outages diesel generators are increasingly being used as a backup possibility to ensure electricity supply (Foster & Steinbuks, 2009). This generator usage leads to increased air emissions and health issues (Pronk et al., 2009; McDonald et al., 2011). For sub-Saharan Africa, the fossil fuel energy consumption increased by a factor of 1.5 to 1000 compared with current grid levels (Farquharson et al., 2018). Furthermore, Farquharson et al. (2018) estimated that the cost of using diesel generators ensuring the power supply is extensively more expensive than the costs of grid electricity in all observed SSA-countries. The impacts of unsupplied electricity as well as the costs of backup electricity may restrict the abilities of firms to flourish (OseniI, 2012).

In addition, the world consumption of primary energies is estimated to further increase by 12% between 2019 and 2030, whereas demand is generally decreasing in advanced economies, the predicted increase is expected to take place in developing countries and emerging markets (International Energy Agency, 2020). The large share of coal-based electricity generation significantly increased the emission rate negatively affecting environmental concerns (Dabrowski et al., 2008). In order to meet the climate reduction targets of the Paris agreement and enable general access to reliable and sustainable energy, it is necessary to increase the usage of renewable energies. This will furthermore increase the pressure on the electricity grids in South Africa.

The multiple impacts resulting from lacking, unreliable, and unsustainable electricity on the economy, together with environmental and social aspects, highly motivate the importance of including energy poverty issues in development conversation (Bridge et al., 2016a) and promoting a transformation of the electricity system in South Africa. Technical opportunities addressing these issues will be presented in the following chapter.

2.2 Smart Grid-Role for Sustainable Development in South Africa

The power grid is a naturally evolved system that is composed of different types of sub-grids. Due to its high complexity and critical function, changes and further development processes are time-consuming and exertive. This inertia has meant that most power grids are not equipped to deal with current challenges, such as climate change, pollution, resource scarcity, and poor working conditions (Caputo et al., 2018; Fang et al., 2012). The current power grid is designed for centralized electricity production in large power plants that often use fossil fuels (Dileep, 2020). In this system, electricity flows from centralized power plants to electricity consumers and information flows from electricity consumers back to electricity producers. The amount of available information, however, is severely limited (Dileep, 2020).

The South African grid is based on the twentieth century technology and is accordingly not prepared for the challenges of the current century. In order to address the identified sustainability challenges the smart grid domain plays a particularly important role in the context of the electrical power grids (Caputo et al., 2018). There is currently no uniform definition existing for the term smart grid. It can be generally defined as the transformation of an analog power grid to a digital power grid (Dileep, 2020). This transformation should enable a two-way flow of information and power. Additional information should be collected in order to identify the power grid status. Automated analyses and control mechanisms should be furthermore established to harden the grid and increase security. Electricity production has to change from centralized to an increased decentralized electricity production, relying more on renewable energy replacing fossil fuels (Arritt & Dugan, 2011). A critical factor for the transformation to the smart grid is the data obtained. This can be ascertained through advances in ICT (smart meters, 5G, wireless; Ahmad et al., 2017; Hui et al., 2020). On the one hand, the collected data provides a fine granular overview of the power grid status, and on the other hand, further concepts can be developed on the basis of this data, such as electricity production and consumption predictions (Sect. 3). These forecasts, together with the collected information, can be used to operate the grid (Sect. 4.4) or to identify expansion potentials.

ICT can be understood as an instrument to support an effective use of the finite resources, aligning supplier and consumer behavior with sustainability requirements (Steinmüller, 2001), distributing electrical energy over space and time and shifting energy consumption. The smart grid network can schedule the resource usage in time by postponing specific tasks to low-demand hours and reallocating the resource usage in space to utilize the energy surplus to another location (Caputo et al., 2018). Access to broader demand and supply information can address multiple sustainability challenges that occur with the production and distribution of electricity (Ngar-yin Mah et al., 2017). ICT-enabled energy grids aim at improving efficiency, load balancing and are intended to encourage consumers in optimal energy use through different mechanisms, such as setting prices (Kadlec et al., 2018). This enables emissions savings contributing positively to climate change targets. The resulting system efficiency can lead to economic gains, job creation, and system resilience (Meadowcroft et al., 2018). Smart grids have the potential to contribute effectively to a sustainable energy transition (Ngar-yin Mah et al., 2017), as they can help enable large-scale integration of renewable resources and increase the inflow of electrical energy (Kadlec et al., 2018). When increasing availability of a resource and therefore adding additional power stations of solar, wind, or water energy to an energy network, these energy resources must fit the technical conditions of the system in order to improve the value of it. ICT can be implemented as an extension tool supporting the integration of additional power stations (Caputo et al., 2018).

The existing technology in South Africa is in a poor condition, as the power grid has not been adequately maintained and expanded (Masembe, 2015; Eberhard et al., 2008; Nwaiwu, 2021). Consequently, smart grid technologies have not been implemented. Masembe (2015) was able to show that the implementation of modern smart grid technologies could achieve an improvement in terms of the availability of electricity and the duration of power outages for end consumers. Maintenance, modernization, and expansion of the existing grid infrastructure, together with the implementation of smart grid technologies would, however, have the potential for greater improvements (Masembe, 2015; Farquharson et al., 2018). This effect has also been observed in other studies and is therefore not exclusively applicable to South Africa. Decisively, the condition of the power grid is the significant factor (Balijepalli et al., 2004; Subban & Awodele, 2013; Yoldas et al., 2019). An additional challenge is the lack of political effort in this regard (Nwaiwu, 2021).

3 Methods for Forecasting Electricity Demand

Forecasting, as previously mentioned, is a critical component of a smart grid as it is needed for both demand and energy generation predictions, which in turn are necessary for reliable planning. The technical methods used to realize these forecasts can be typically categorized into conventional- and artificial intelligence (AI)-based approaches (Wei et al., 2019). While conventional approaches mainly include time series, regression, and grey models (Foucquier et al., 2013), AI-based models include artificial neural networks or support vector machines (González-Briones et al., 2019). The following sections explain the key differences between these approaches, as well as the relevant work that has been conducted in the area of electricity demand and -generation forecasting, in order to elaborate promising methods, improving the systems plannability.

3.1 Conventional Approaches

In the field of energy consumption forecasting, the most common time series models are the autoregressive (AR) and the moving average (MA) model (Wei et al., 2019). In an AR-model, it is assumed that the current value of a series can be explained as a linear function of its n past values (Shumway et al., 2000). In this context, "autoregressive" refers to the fact that there is a regression of the variable against itself. In contrast to the (left-hand) linear combination of past values in the AR-model, the MA-model assumes that the white noise on the right-hand side of the defining function is linearly combined to form the observed data (Shumway et al., 2000). Both the AR- and MA-models require only a small amount of historical data, which considerably simplifies their construction (Wei et al., 2019). Since external factors can play a significant role in predicting energy consumption or generation, different variants and combinations of AR models have been developed over the years. These include Autoregressive Moving Average Methods—ARMA (Pappas et al., 2010; Huang et al., 2012), Autoregressive Integrated Moving Average Methods—ARIMA (Abdel-Aal & Al-Garni, 1997), or Seasonal Autoregressive Integrated Moving Average Methods—SARIMA (Zhu et al., 2011).

Also linear, nonlinear, and logistic regression models have been used for energy consumption forecasting, with the latter being one of the first approaches to be applied in this field (Wei et al., 2019). Linear regression assumes that an output—in this case a dependent time series—is influenced by a collection of possible inputs—in this case an independent series (Shumway et al., 2000). This regression type has been applied, for example, by Pourazarm and Cooray (2013) and Viloria et al. (2020) for electricity consumption forecasting and by Abuella and Chowdhury (2015) for electricity generation forecasting. In contrast to linear regression, nonlinear regression is characterized by the fact that the prediction function depends nonlinearly on one or more unknown parameters. Following this argumentation, Kumru and Kumru

(2015) used nonlinear regression models to include specific calendar events in short-term electricity demand forecasting (Kumru & Kumru, 2015). Logistic regression—i.e., the value into which the independent variable can result is limited—has been applied to electricity forecasting, for example, by Fuks and Salazar (2008).

According to the grey-model-theory, known information is considered white, unknown information is considered black, and semi-known (i.e., lacking or unreliable) information is considered gray. In order to extract possible rules for time series prediction, grey models investigate the sequence of primary discrete data and transform grey difference equations into grey differential equations (Balochian & Baloochian, 2021). They belong to the category of non-statistical models for predicting nonlinear time series, which are particularly useful when a sufficient number of observations are not available (Xie & Liu, 2005). Grey models have been widely used for forecasting electricity demand or prediction, with promising results (Wang et al., 2018, 2018, 2020; Ding et al., 2018; Elgharbi et al., 2019).

3.2 AI-based Models

With the advent of artificial intelligence and today's expanded computational capabilities, artificial neural networks (ANN) have been increasingly used to forecast energy demand and generation. ANNs consist of interconnected artificial neurons and are capable of mapping even very complex, nonlinear dependencies within the input information. To this day, many different variants of ANNs have been developed, which differ primarily in their underlying architecture. Within the research field of electricity consumption or generation forecasting, these variants include Adaptive Fuzzy Neural Networks (Chang et al., 2011), Back Propagation Neural Networks (Yang et al., 2016), Wavelet Neural Networks (Zhang & Wang, 2012; Zhang et al., 2018), Autoregressive Neural Networks (Bâra & Oprea, 2018), and Recurrent Neural Networks (Kermanshahi, 1998; Marino et al., 2016).

Another category within AI-based approaches are the Support Vector Regression models (SVR) which are derived from the Support Vector Machine. These models rarely run the risk of falling into the typical disadvantages of neural networks. The latter are, on the one hand, overfitting—i.e., the undesirable property of a neural network to describe random errors or noise instead of the underlying relationship—and, on the other hand, the exponentially increasing complexity with each additional data dimension (Ceperic et al., 2013). Moreover, by avoiding these potential drawbacks, SVR approaches achieved good results in the context of electricity consumption and generation forecasting (da Silva Fonseca et al., 2011; Cao & Wu, 2016; Yaslan & Bican, 2017; Shine et al., 2018).

4 Deep Reinforcement Learning for Power Grid Control

The use of automation technologies is a central component of the transformation to a smart grid system. In this context, various artificial intelligence approaches are being researched. Artificial intelligence offers the possibility to generate additional information (Sect. 3), together with the fact that these systems can be used for control and (partial-)automation processes (Zhang et al., 2019). Thus, AI has already been researched in the areas of energy management, demand response, electricity market, and operational control and the current state of research has been compiled by Zhang et al. (2019). Reinforcement Learning describes acting artificial intelligence algorithms, which interact with their environment and evaluate their steps to optimize themselves. The term Deep Reinforcement Learning covers methods that use artificial neural networks. However, there are also other methods that can be assigned to the categories of Temporal-Difference Learning or Dynamic Programming (Sutton & Barto, 2018). Solutions involving Deep Reinforcement Learning are presented and discussed in the following chapters for different categories and subareas of smart grid systems.

4.1 Energy Management

Energy management combines demand, consumption, and storage possibilities and tries to solve resulting problems. It is particularly important in the context of decentralized microgrids, since the most efficient use of local renewable energies is required. As a result, effective energy management can promote the integration of renewable energy. Furthermore, the demand-based storage of electricity is possible, taking into account the market price (Zhang et al., 2019). Energy management can refer to household-related situations, electric vehicles as energy storage, or the grid itself. Both household-related use cases and the usage of electric vehicles require the cooperation of private individuals. Whereas the establishment of management systems within the grid can start independently of these. The survey mainly observes procedures that are driven by economic aspects. All considered methods have the goal of reducing costs or promoting the use of self-produced electricity, using reinforcement learning methods based on Q-values (Zhang et al., 2019; François-Lavet et al., 2016; François-Lavet, 2017). The efficient use of locally produced electricity in particular represents a great opportunity for South Africa, as the grid infrastructure is unable to transport the increasing electricity demand from central power plants to the consumers. Decentralized electricity production can thereby efficiently relieve the distribution network.

4.2 Demand Response

Demand response describes the provision of electricity in line with demand. This is usually done by changing the price or other incentives. The aim is to increase grid stability and reduce possible peak loads by shifting them (Zhang et al., 2019). The distinctive feature here is that both parties are taken into consideration: producers and consumers. The inclusion of the latter is a necessary innovation for the smart grid, as the controllability of producers is limited due to renewable energy implementation (Hui et al., 2020). By taking controllable loads effectively into account, for example, if a particularly large amount of electricity is produced at a time when consumption is low, HVACs can be used to sensibly intercept this peak load. Other methods involve optimizing charging cycles of storage units or of electric vehicles (Zhang et al., 2019).

4.3 Electricity Market

In general, an electricity market describes a trading place where electricity quotas are offered. Markets can be divided into two segments, wholesaler and customer markets. Wholesaler markets are usually organized as exchanges, where electricity producers offer their quotas and retailers buy these to sell to their end customers. Furthermore, sales to end customers can be seen as an additional market (Zhang et al., 2019). Trading can be done using DRL, whereby a good strategy can reduce costs in this process. This situation is often modeled as game theory, due to the competing actors. Zhang et al. (2019) show that DRL is able to act on energy markets and reduce costs. This part of the smart grid is not applicable to South Africa, however, due to the fact that Eskom has a monopoly or a quasi-monopoly in many areas (Kenny, 2015) and therefore no market is available.

4.4 Operational Control

Operational Control includes the explicit control of power generators and loads. For power generation, DRL is able to facilitate control from a centralized system to a decentralized system, overcoming the shortcomings of centralized systems as a result. Furthermore, various control systems could be developed for wind turbines or other renewable power generators, which can improve their efficiency (Zhang et al., 2019). Challenges in the context of load control are the state estimation in addition to actual control, since fine-grained knowledge about individual households, for example, is often lacking. In this regard, LSTMs or CNNs are used for state estimation. DRL is then used as a performing control method (Zhang et al., 2019).

5 Chances for South Africa: A Business Opportunity

South Africa is uniquely positioned in transitioning to a smart grid system and increased sustainable power production due to Eskom's state monopoly. Many well-known models incorporate market approaches, which is not currently feasible for South Africa. The current situation, however, offers opportunities. For example, the establishment of off-grid microgrids is conceivable and these scenarios have been extensively evaluated for rural areas (Patel & Chowdhury, 2015; Hubble & Ustun, 2018; Longe et al., 2017; Motjoadi et al., 2020). On the one hand, Patel and Chowdhury (2015) identified technical, as well as economic challenges and found that from an economic perspective, cheap electricity from low quality coal is the main barrier to establishing sustainable electricity production. Photovoltaics, on the other hand, are greatly suitable throughout the country, whereas other sustainable electricity production plants such as wind energy or hydroelectric power plants are only viable in parts—being limited by the costs involved (Patel & Chowdhury, 2015). From an economic point of view, the establishment of sustainable microgrids is unlucrative due to the cheap coal-fired electricity. However, social as well as economic aspects have been ignored in this consideration. Some rural areas, for example, are still not connected to the national grid (Motjoadi et al., 2020) leading to economic, environmental, and social challenges in addition to health issues (Pereira et al., 2011). Off-grid microgrids also present a particular challenge in this regard, as they are not connected to a national or international power grid. As a result, the power supply must be compensated by the existing electricity production and an accordingly adapted consumption. This adaptation and control can be ensured and optimized by the methods presented in Sects. 3 and 4. Due to its decentralized nature and independence from the national power grid, such a microgrid can be operated by small communities independent of external partners (Van Acker et al., 2014). A possible microgrid was developed by Longe et al. (2017) but currently still uses relatively strict consumption values. The potential of such a grid could be improved by using advanced forecasting strategies and incorporating DRL control systems.

Asmus and Lawrence (2016) have listed various business models in the context of off-grid microgrids. One possible area is software provided as a service. However, the current focus is increasingly on the construction and operation of such microgrids, simultaneously being a highly complex area and requiring creative solutions (Asmus & Lawrence, 2016). As shown, off-grid microgrids represent a great opportunity for independent power supply, but at the same time the operation can be seen as a complex control problem due to the closed nature of the system and the limited predictability of renewable energy. Recent advances in predictive models and DRL for power systems offer great opportunities and possibilities to solve this complex problem (compare Sects. 3 and 4), building the foundation for new business models. These can enhance software as a service, in particular AI. Most customers prefer plug and play solutions, so outsourcing AI can also be seen as a possibility (Asmus & Lawrence, 2016).

A resulting business model opportunity will be illustrated in the following by using the Lean Canvas model. Provision and maintenance of AI models for the control of components of the microgrid, together with the management of the microgrid to prevent blackouts, can be seen as the *problem* being addressed. Control and prediction models need to be implemented and be adapted beforehand to the respective microgrid. Microgrids usually operate a large number of sensors that produce data that is incorporated into the dataset and used to create the AI models. The data exploration and data cleaning, subsequent model creation and constant optimization would then be done in the cloud or on in-house hardware. The execution of the models can then take place either on the customer's premises, which requires its own hardware for this purpose, or likewise, in the cloud or on its own systems. Execution in the cloud or on the customer's own hardware offers an additional, regular source of revenue. Execution on hardware within the smart grid is necessary if the smart grid has no Internet access. Software as a service is therefore the provident *solution* to the identified problem. The *unique selling point* would be the all-in-one solution of needs analysis, development and maintenance of AI models. As previous providers are not specialized on microgrid control, but general IT service providers are, the complexity involved leads to much higher costs. Should the customers' data be stored, the data set becomes a *major advantage*, as it can facilitate training immensely and, based on similarity metrics, the creation of new models can be significantly improved. Furthermore, the exchange of data between microgrids can also lead to an improvement. Especially in the context of network expansion or optimization, empirical values from other microgrids can provide the necessary information for demand-driven expansion. *Customer Segment* includes operators of the microgrids, which can be municipalities, companies, or private individuals. Eskom's market monopoly position also affects the know-how of possible competitors. Possible microgrid operators have to newly develop the market, as there are no competitors besides Eskom. These customers can compensate for the lack of experience by using the described service. The *contact channel* depends on the type of customer. Customers who currently have no access to the electricity grid would probably have to be contacted personally, e.g., in a consortium consisting of companies that are needed for the smart grid establishment. Since there are already some off-grid microgrids, a direct contact would also be feasible, due to the fact that the number of potential customers is small, and the application area is complex and very individual. In this context, free demand analyses could be a viable approach. A cooperation with hardware manufacturers is also conceivable. The first important *key figure* should be the number of managed microgrids. These could then be divided into online (cloud-based) and offline (on site) solutions. Furthermore, the number of AI models is a good metric, as it depends on the size of the respective microgrids. The efficiency of the workflow could be ascertained by measuring the deployment time. The more efficient the workflow is and the better the existing models can be reused, the higher the efficiency. The performance of the models could be determined by the network state. In addition to this, the number of power outages could be measured. However, these key figures are not exclusively dependent on the performance of the AI, but also on the expansion of the microgrid. Here,

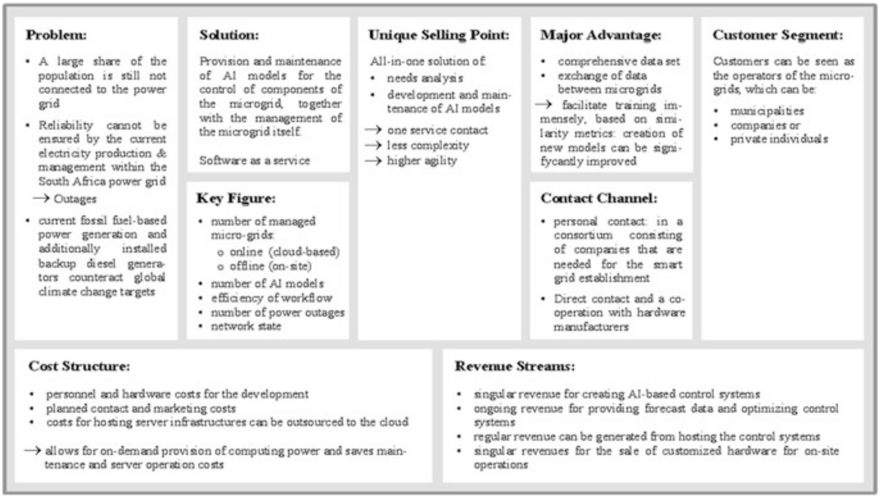

Fig. 1 Resulting business model opportunity illustrated using the Lean Canvas model (own illustration)

a differentiated analysis of the reasons for critical network conditions is essential. The *costs structure* consists of personnel and hardware costs for the development, together with planned contact and marketing costs. The costs for hosting server infrastructures can be outsourced to the cloud, which allows for on-demand provision of computing power and saves maintenance and server operation costs. *Revenue streams* include singular revenue for creating AI-based control systems, as well as ongoing revenue for providing forecast data and optimizing control systems. Ongoing costs are closely tied to singular revenues, as control systems ideally use forecast data for decision-making, and adjustments to network infrastructure, climate changes, or changing usage patterns require adjustments to control systems. In addition to building the models, regular revenue can be generated from hosting the control systems, as well as, singular revenues for the sale of customized hardware for on-site operations.

The approach described must be seen as part of a holistic solution and cannot simply be adopted for the whole of South Africa in general. It can be implemented especially in rural areas or individual city districts, provided that they can produce enough electricity. Larger cities or entire urban centers require more complex solutions. A long-term desirable goal would be the interconnection of individual microgrids forming a grid network. For the business model, the acquisition of data is a critical factor, as is market establishment. The concept is based primarily on know-how and requires a high degree of symbiosis with other companies in the industry (Fig. 1).

6 Summary and Conclusion

The current state of the South African power grid management and infrastructure leads to various sustainability issues reaching from environmental effects, caused by the dominant position of coal energy in the energy mix and additionally installed backup diesel generators to challenges due to the unreliable or lack of access to electricity. The latter results in major social, economic and environmental drawbacks and restrains development. Technologies used within the grid are not suitable for the needs of the twenty-first century. Therefore, there is a necessity for a power grid transformation, offering opportunities to establish a smart grid and addressing existing challenges. Smart grids can enable the integration of decentralized produced renewable energies, together with a two-way information and power flow. ICT can be understood as an instrument to support an effective use of the finite resources, aligning supplier and consumer behavior with sustainability requirements, distributing electrical energy over space and time and shifting energy consumption. Resource usage can be rescheduled by postponing specific tasks to low-demand periods and reallocating the spatial resource usage utilizing energy surpluses to other locations. An important factor of the smart grid is the prediction by and the usage of artificial intelligence. Forecasting is needed for both demand and energy generation predictions. The use of automation technologies is a central component of the transformation to a smart grid system. Artificial intelligence offers the opportunity to generate the additional information needed and can be used for control and (partial-)automation processes. The complex control of such volatile and ever-changing systems requires an adaptive and performant solution, here artificial intelligence from the field of deep reinforcement learning can be seen as a possible solution. These presented technologies enable the construction and maintenance of off-grid microgrids, which can be built more efficiently than a complete grid modernization. The identified solutions have the potential for laying the foundations for a sustainable business opportunity in this context. A service company could be established, since these technologies require special hardware and specific know-how. Nevertheless, this approach is not evenly feasible throughout South Africa in general, targeting rural areas or individual city districts in particular, aiming at interconnecting individual microgrids to a grid network. The presented concept additionally requires a high degree of symbiosis with other companies in the industry. It also has to be considered that current policies and framework conditions might act as barriers toward a sustainable transformation of the entire power grid and could therefore be a valuable field for further research in this context. The presented solutions in this paper have, however, the ability to contribute to a future, where the integration of renewable energies in interconnected, decentralized microgrids, as well as the distribution of electrical energy over space and time, preventing supply bottlenecks, provides the plinth for an affordable, reliable, and sustainable access to electricity for all.

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Sustainable Digital Entrepreneurship: Examining IT4Sustainability as Business Development Path

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Abstract There is an increasing interest within the field of Information Systems as well as political agendas to identify the potential of digital technologies to promote sustainable development. Nonetheless, sustainable entrepreneurship and digital entrepreneurship are widely treated separately within the literature, suggesting that there is little understanding of how entrepreneurs could employ digital technologies to promote sustainable development. Based on an empirical, qualitative research approach, relying on Grounded Theory methodology, this paper identifies characteristics of sustainable digital entrepreneurs. An investigation of the manifestations of the sustainable digital orientation reveals a rather diffuse understanding of the relation and potential synergy effects. In response to this gap, the paper presents examples on how sustainable digital entrepreneurs employ digital and disruptive technologies to tackle sustainability challenges (IT4Sustainability development path), including information and communication technology, such as digital platforms, artificial intelligence, or drone technology. The presented approaches range from second-mover approaches associated with low digital maturity limited to the business level to the development of new business models facilitating the sustainable transition of whole sectors. These insights are summarized in an IT4Sustainability maturity model, which presents different starting points for entrepreneurs. Relevant

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theoretical, practical, and policy implications are discussed, especially concerning the education on IT4Sustainability, including Corporate Digital Responsibility.

Keywords IT4Sustainability · Digitalization · Sustainability · Entrepreneurship

1 Introduction

There is an increasing interest within the academic fields of Information Systems and sustainability management as well as political agendas to identify the potential of information technologies (IT) to promote sustainable development, hereafter referred to as IT4Sustainability (IT4S). Overall, there is a common agreement on the potentially positive or negative contribution of digital technologies to sustainable development. Following Gregori and Holzmann (2020:2), "digital sustainability [describes] the organisational activities that seek to advance the sustainable development goals through creative deployment of technologies that create, use, transmit, or source electronic data." Despite the central role of companies as big data collectors, generators, and utilizers in the sustainability context (Lock & Seele, 2017), sustainable entrepreneurship (e.g., Schaltegger & Wagner, 2011; Shepherd & Patzelt, 2011) and digital entrepreneurship (e.g., Bandera & Passerini, 2018; Nambisan, 2017) are widely treated separately within academic literature. Thereby, potential synergy effects are under-researched (Gregori & Holzmann, 2020).

The purpose of this paper is to present an integrative view on sustainable and digital entrepreneurship and emphasize the role of IT4S as a management issue. Using an empirical approach relying on Grounded Theory methodology, this paper attempts to partly fill the described research gap in two steps: First, by identifying characteristics of sustainable digital entrepreneurs. Second, by providing examples of how these entrepreneurs employ IT to promote sustainability. The sample consisted of owner-managers of digital-resilient small and medium-sized enterprises (SMEs) and Start-Ups.

1.1 Sustainable and Digital Entrepreneurship

In both fields, various entrepreneur typologies have been developed. Yet, the integrative view on sustainability and digitalization in entrepreneurship research presents a very young stream of research (Bican & Brem, 2020; George et al., 2020; Satalkina & Steiner, 2020), leading to RQ1: *What are characteristics of sustainable digital entrepreneurs*?

Previous works on sustainable entrepreneurship provide a thorough understanding of sustainable entrepreneurs (SE) (e.g., Choi & Gray, 2004; Choongo et al., 2019; Schaltegger & Johnson, 2021; Schaltegger & Wagner, 2011; Taylor & Walley, 2004). SEs create companies that substantially reduce environmental impacts and increase the quality of life (Schaltegger & Wagner, 2011; Schaltegger & Johnson, 2021), thus pursuing environmental and social causes (Choi & Gray, 2004). The generation of ideas (discovery and opportunity phase: Schaltegger & Johnson, 2021) is a result of SEs' dissatisfaction with available alternatives or idealism (Choi & Gray, 2004). Thus, sustainability motives of entrepreneurs have been frequently investigated (Gast et al., 2017; Stubbs, 2017; Taylor & Walley, 2004; York et al., 2016). In contrast to this, digital entrepreneurship (e.g., Ammirato et al., 2019; Giones & Brem, 2017; Kraus et al., 2018) presents a very young field of research. Digital entrepreneurs (DE) create new ventures or transform existing businesses by developing novel digital technologies or experimenting a novel usage of such technologies (Elia et al. 2020). Personality traits, like education and digital capabilities, are dimensions of specific interest (e.g., Bandera & Passerini, 2018; Li et al., 2018; Satalkina & Steiner, 2020).

1.2 IT4Sustainability (IT4S)

The relationship between organizational sustainability and digitalization, including IT4S, is increasingly discussed in different academic fields (e.g., Hilty & Aebischer, 2015; Isensee et al., 2020; Kostoska & Kocarev, 2019; Penzenstadler et al., 2014; Wu et al., 2018). Griese et al. (2018) show that in simultaneously pursuing digitalization and sustainability, businesses can increase their resilience.

Twenty years ago, Berkhout and Hertin (2001) already specified five areas in which information and communication technologies (ICT) can help optimize the production process and thereby decrease energy consumption, including intelligent product design, supply chain efficiency, and new work organization, e.g., teleworking. According to Gregori and Holzmann (2020), digital technologies enable three novel configurations of sustainable business model components: (i) blended value proposition (aggregation of environmental, social, economic value); (ii) integrative value creation (increased connectivity and co-creation of actors); (iii) multidimensional value capture (complementary influences, such as increased scalability or value spill over). Within a position paper, Renn et al. (2020), for example, point toward the potential of digital platforms to increase ecological efficiency of communicative and coordinative services, as they use less mobility, space, and material. However, following Bican and Brem (2020), it should be emphasized that the potentials of IT4sustainability will not be achieved automatically. Instead, scholars and entrepreneurs alike need to develop a vision on IT4Sustainability and Corporate Digital Responsibility (Penzenstadler et al., 2014; Jacob, 2019). Consequently, RQ2 was formulated: *How do sustainable digital entrepreneurs employ IT4Sustainability?*

Table 1 Sample description

ID	Function	Gender	Business form	Staff	Foundation	Sector
E1	Sustainability manager	m	SME	250	2003	Manufacturing (food & beverage)
E2	Owner-manager	m	Start-Up	3	2011	Information and communication
E3	Owner-manager	m	SME	100	2000	Energy
E4	Marketing & distribution	m	SME	35	1989	Information and communication
E5	Owner-manager	m	SME	100	1907	Manufacturing/ handcraft
E6	Chief technical officer	m	Start-Up	10	2018	Agriculture
E7	Owner-manager	m	SME	14	2013	Energy
E8	Owner-manager	m	Start-Up	3	2018	Information and communication
E9	Owner-manager	m	SME	35	1977	Construction
E10	Finance & HR manager	f	SME	8	2016	Wholesale
E11	Owner-manager	m	SME	100	1973	Consulting
E12	Owner-manager	f	Start-Up	5	2018	Retail/handcraft

2 Research Approach

An empirical research approach following Grounded Theory was chosen (Charmaz, 2014; Glaser et al., 1968). Semi-structured telephone interviews with open-ended questions[1] were conducted between 18 May and 30 September 2020 in German. The interviews lasted between 25 and 61 minutes, and audio files were transcribed verbatim. The interviewers consisted of the leading researcher and two student assistants of a Bachelor program in business psychology. The final sample consisted of twelve (owner-) managers of digital-resilient SMEs and Start-Ups from different sectors in Germany (Table 1). Herein, SMEs include companies with a maximum of 250 employees. Start-Ups are included within this threshold but further defined as companies with highly innovative business models, products, or services striving for growth that are younger than ten years (Olteanu & Fichter, 2020). The computer-assisted coding and analysis process followed the steps of thematic analysis (Braun & Clarke, 2006). Digital-resilient businesses would evaluate their levels of sustainability and digitalization as relatively high compared to their sector (Griese et al., 2018).

[1] Interested readers can receive the interview guide from the authors upon request.

3 Findings

The selected main characteristics of sustainable digital entrepreneurs (SDE) observed across the sample (Sect. 3.1) extend the frequently applied person-opportunity nexus in also emphasizing SDEs' engagement in institutional development (Sect. 3.1.1). Furthermore, while Bican and Brem (2020) observed that firms often lack a clear understanding of digital topics, such as digital business models, digital entrepreneurship, or digital transformation, it seems important to investigate SDEs' green digital orientation (Sect. 3.1.2). Section 3.2 presents exemplary IT4S approaches employed by SDEs.

3.1 Sustainable Digital Entrepreneurs

SDEs show specific *personality traits*, such as a strong sustainability ambition (purpose-driven), persistence, and unconventionality. The *main goal* of their venture is to positively contribute to sustainable development. More specifically, their *core motivation* is to present an alternative to the Status Quo, especially regarding the environmental performance of specific sectors or Human Resource Management (e.g., regarding HR management/leadership approaches). Specific prerequisites frame how strongly the SDE strives for *business growth*. These were often related to maintaining the organizational culture, such as securing transparency and sustaining low hierarchies. *Opportunity recognition* is improved through an integrative view on sustainability and digitalization (green digital orientation, Sect. 3.1.2), which includes testing for opportunities to improve sustainable performance through adapting digital technologies. Furthermore, sustainable digital entrepreneurship can be understood as a s*ocial movement* (Schaltegger & Johnson, 2021). More specifically, SDEs use the position of the business to influence the macro-environment (and thus facilitate sustainable digital transition on organizational, sectoral, or societal levels). In particular, the element of *creative disruption* is realized through breaking up common thought and behavioral patterns within (Sect. 3.1.1) and outside the business.

3.1.1 Institutional Development (Organizational Culture)

The challenging of commonly held beliefs, values, and practices emphasizes the central role of organizational culture in sustainable digital entrepreneurship (e.g., Isensee et al., 2020; Warrick, 2017). From this, a bi-directional relationship between the entrepreneur and the organizational culture can be hypothesized, in which the SDE is part of the organizational culture and at the same time influences the organizational culture. Conversely, SDEs successfully create a digital-resilient business by shaping and professionalizing the organizational culture and employing different digital technologies to fulfill this task. Three different approaches were observed across the sample (*diffuse; dominant; visionary*). Even though SDEs with a *diffuse* approach somehow engage in culture development and create cultural artifacts, they cannot clearly articulate the role of the organizational culture for sustainable, digital development, as shown in the following statement by E12. A possible explanation is that some SDEs are predominantly externally oriented. In other words, SDEs with a strong customer or market orientation might insufficiently focus on institutional development.

> *"What would [the organizational culture] have to do with sustainability and digitalization?"* (E12)

SDEs with a *dominant* approach need to deal with the heterogeneity of sub-groups and reluctance regarding the use of digital technologies, as reflected upon in the statement below by E5. While such SDEs already hold strong sustainable digital values, these need to be disseminated throughout the business.

> *"Above all, we have to foster the willingness to use the system."* (E5).

SDEs with a *visionary* approach strategically professionalize the sustainable digital organizational culture and thereby create value for internal and external stakeholders. The following statements reveal SDEs' reflection on whether individual members actually identify with the organizational culture.

> *"That was important to us . . . just to get a picture and thereon somehow develop something each and everyone can identify with.*" (E10).
>
> *"But I believe we have a very, very close, open, and personal exchange. And I believe everyone is quite satisfied with the working atmosphere, with the culture, the way we are doing it there."* (E7).

The following statements show that companies with visionary culture development approaches developed a joint purpose (Harris & Crane, 2002) that is somewhat associated with IT4S.

> *"We are developing systems to support organizations in solving sustainability tasks."* (E8).
>
> *". . . the will of digitalization . . . is unrestricted among all employees."* (E7).

On the other hand, SDEs are influenced by organizational culture and sometimes actively seek to initiate their personal learning process (Li et al., 2018) through establishing bottom-up culture development approaches, such as a digital idea management system with incentives.

3.1.2 Green Digital Orientation

The statements below suggest that SDEs at least have a general understanding of the complex relationship between digitalization and sustainability.

> *"In our particular case, the topics are relatively separate."* (E1).
>
> *"Something between complementary and separate."* (E8).

While more than half of the interviewees (E2, E3, E4, E6, E7, E9, E10) assume a complementarity, it can be concluded that SDEs are generally aware of the potentials of digitalization, such as increased transparency about the sustainability performance or new business opportunities facilitating sustainability.

"Also, to really prove our sustainability." (E6).

"We are currently developing a tool that allows us to determine the actual carbon footprint of the supply chain." (E8).

Depending on the sector or the aspired sustainable transition, digitalization is even recognized as a necessary condition.

"From this point of view, innovative sustainability is not possible without the digital. At least not in my business." (E7).

At the same time, SDEs are aware of the negative impact on sustainability (E6, E8, E10, E12), for example, because "*more resources and more energy are consumed*" (E8). Thus, as "*digital is not necessarily sustainable*" (E11), SDEs have a basic understanding that the sustainability of employed digital technologies needs to be considered (Corporate Digital Responsibility: Jacob, 2019).

"At some point we tested our homepage to see how sustainable it really is, with loading times and how much energy it needs. We partially consider such aspects . . . but it is not yet an overall concept." (E10).

"For us, the technology or the product is always sustainable, as good as it can be." (E6).

3.2 IT4Sustainabilty as a Business Development Path

Table 2 summarizes the observed IT4S approaches ordered by the level of interference with sustainable development. Digital technologies mentioned by the participants to tackle environmental challenges include digital platforms (E2, E9, E10), digital twin (E6, E11), cloud technology, artificial intelligence (AI), including NFC tracking (E9), automation, and drone technology (E6). The COVID-19 pandemic especially fuelled the realization of digital customer access, even for companies with an analogue product or service (E12), and the application of mobile technologies for teleworking, leading to reduced travel activity (E7, E9). Some SDEs take a second-mover approach toward IT4S and try to keep up with the opportunities while "*urgently waiting for better solutions*" (E3). Overall, two different orientations become apparent. The *internal orientation* (Sect. 3.2.1) is limited to the business context (e.g., process optimization). The *external orientation* (Sect. 3.2.2) pushes the focus beyond the business context. In other words, SDEs can employ digital technologies to enhance the sustainability performance of their business (user) or those of customers or whole sectors (enabler).

Table 2 Observed IT4Sustainability approaches

ID	IT4S approach
E12	• digital customer access (main service/products remain analogue).,
E4	• enabling paperless office for customers.
E1	• reflection on the potential of digitalization to optimize the return-system for drinking bottles.
E3	• paperless office, • business-science collaboration to explore potential applications of artificial intelligence for plant control.
E5	• digital system control, • use of mobile technologies for work organization.
E6	• digital ideas management system, • use of digital technologies for enhanced transparency on sustainability performance, • use of drone technology for data analysis on cropland, • digital monitoring and automated control of crop growth, • application of digital twin technology for crops.
E7	• digital plant monitoring, • use of mobile technologies for work organization and reduction of travel activity.
E9	• mobile work/video conferencing (reduced travel activity), • NFC Tracking for improved plant machine care.
E11	• application of digital twin technology for system monitoring and control (predictive maintenance), • paperless office.
E10	• wholesaler with a digital platform focused on the mediation between providers of organic food rejected by supermarkets and potential customers.
E8	• digital product: Blockchain-based tool to assess supply chain carbon footprint.
E2	• digital service: Digital platform (marketplace) for wind turbines.

3.2.1 Internal Orientation

SDEs recognize digital readiness as a valuable resource and distinguishing factor. Thus, they are aware of the need to increase digital competencies for a successful application of IT4S.

> *"Principally, we can operate completely digital. And that is also an extreme distinguishing feature."* (E11).
>
> *"I believe that the topic, simply to be able to work digitally and with innovative tools, is also a fundamental requirement for the employees, and ultimately to be competitive."* (E7).

Nonetheless, SDEs are open to external expertise if the development of digital competencies cannot keep pace with the fast development of digital technologies.

> *"In fact, regarding digitalization, we mainly work together with experts because we completely lack the Know-How. … With our dangerously superficial knowledge we do not know what the trend will be the day after tomorrow."* (E11).

Some SDEs use digital technologies for an increased product life through timely maintenance of plants or enhanced transparency and collaboration on sustainable performance.

"We work a lot with digital tools, for example, Slack or now obviously a lot via Zoom." (E10).

E5 presents a good practice of an internal blended value proposition. In this company, the use of digital technologies originally employed for process optimization facilitates the inclusion of people speaking different languages (diversity management; social sustainability).

3.2.2 External Orientation

More proactive SDEs are motivated to promote socio-ecological transformation beyond their business. This can manifest in different ways. In some cases, SDEs achieve increased sustainability value for costumers through a digital product or service (E2, E7, E8, E10). For example, E7 used digital plant monitoring to control energy plants, thus helping customers achieve the energy transition.

"That they will be supported by all means to successfully master this energy transition." (E7).

Even more innovative SDEs drive the sustainable transition of traditional sectors in which digitalization does not play a significant role at all (e.g., handicraft). In at least reflecting on or trying out potential applications of digital technologies to tackle environmental sustainability challenges, SDEs generate new ideas and visions regarding the sustainable transition of whole sectors or industry-wide processes, such as a more efficient reuse system for drinking bottles in the case of E1. E5 and E9 present examples of leading innovators in handicraft. For example, E9 has initiated a research project for developing a digital multi-stakeholder platform solution.

"For example, to manage this reusable system more efficiently, especially the return of empty bottles ..., there, I think, is an enormous potential from a digitization perspective." (E1).

"We also try to educate this industry a little." (E2).

"In my opinion, we do not make use of the available digital possibilities at all ... in the whole craft sector." (E9).

"We see ourselves as ... THE innovation leader in the sector." (E9).

Following the ambition to transform whole sectors or industry-wide processes, SDEs might even create new, fully digital business models. Thereby, particularly visionary SDEs discover and occupy niches in using disruptive digital technologies, i.e., digital platforms (E2) or blockchain technology (E8).

"And the problem is that there are no incentives for the supply chain to reduce its product carbon footprint. With our system, we assess the actual product carbon footprint at every stage of the value chain and then pass it on accordingly." (E8).

4 Discussion

The notion of sustainable digital entrepreneurship addressed in this paper investigates the contribution of entrepreneurial activities (Schaltegger & Wagner, 2011), especially the use of digital technologies and organizational culture development, to sustainable digital development of the business (internal orientation) and whole sectors (external orientation). In identifying the main characteristics of sustainable digital entrepreneurs (RQ1) and examples of the employment of IT4S (RQ2), the main findings (MF) summarized in Table 3 partly extend, support, or specify existing notions on sustainable and digital entrepreneurship. For example, MF2 supports the observation by Bican and Brem (2020) that organizational culture forms a fundamental element of digital entrepreneurship; presents a prerequisite for desirable business growth (Giones & Brem, 2017); presents a novel perspective on entrepreneurship education (Kraus et al., 2018) in suggesting that SDEs are learning through organizational culture, for example, through establishing digital ideas management systems (bottom-up approach).

Figure 1 visualizes the identified maturity levels of IT4S (MF6–8). On the first level, the IT4S application increases the sustainability value on company level (internal orientation). This could include process optimization, improved plant care, organizational culture development, or extended value propositions for individual members or groups of members. The second level increases the sustainability value for external stakeholders. For example, in connecting previously unconnected actors on their digital platform, E10 (wholesaler) increases the share of organic waste and therefore supports sustainable transformation of the food/agricultural sector. On the top level, IT4S forms the technology behind the business opportunity, resulting in new business models fully relying on digital or disruptive technologies which often facilitate the sustainable development of whole sectors. E8 presents an example of a business model that relies on blockchain technology to reduce the carbon footprint of supply chains (Tönnissen & Teuteberg, 2020). Through its digital platform, E2 provides a digital marketplace allowing for a reuse of outdated, yet functional wind turbines, which could enhance the share of renewable energy and promote the transition of the renewable energy sector toward a circular economy (Berg & Wilts, 2019).

5 Conclusion and Outlook

As the potential synergy effects between digital and sustainable development are under-researched and not exploited by practitioners, an integrative view on sustainable entrepreneurship and digital entrepreneurship was presented. Based on an empirical, qualitative research approach, characteristics of sustainable digital entrepreneurs were revealed. Furthermore, examples of the IT4Sustainability

Table 3 Summary of main findings and implications for increased IT4Sustainability maturity

Main Findings (MF)	Implications (for increased IT4S maturity)
RQ1: What are characteristics of sustainable digital entrepreneurs (SDEs)?	
MF1: SDEs show specific personality traits, i.e., sustainability ambitions, dissatisfaction with Status Quo, persistence.	• Practitioners should assess their personality traits and engage in personal development/ coaching and IT4S education. • Governments should develop incentives and support programs for (future) entrepreneurs showing personality traits associated with SDEs.
MF2: SDEs engage in institutional development, i.e., professionalization of organizational culture (*diffuse*; *dominant*; *visionary*).	• SDEs should recognize the professionalization of the organizational culture as a central element of sustainable digital business development. • Practitioners should initiate participative processes for developing a joint purpose on IT4S with which all members can identify. • Entrepreneurs should establish bottom-up culture development approaches that initiate their personal learning process.
MF3: SDEs establish alternative human resource management and leadership approaches.	• Entrepreneurs should accept their role as sparring partners on eye-level with employees (appreciation, trust). • Practitioners should increase employees' digital competencies.
MF4: SDEs achieve high levels of organizational resilience through high levels of digitalization and sustainability.	• Practitioners should determine prerequisites for business growth beyond economic measures (purpose-driven), i.e., develop a Corporate Digital Responsibility. • Governments/Scholars should present good practices of successful and resilient purpose-driven organizations employing IT4S.
MF5: SDEs develop a green digital orientation through an integrative view on sustainability and digitalization.	• Practitioners should assess and strengthen their green digital orientation. • Practitioners should identify the potentials of digital technologies to tackle sustainability issues and, in turn, enhance the sustainability of employed digital technologies.
RQ2: *How do sustainable digital entrepreneurs (SDEs) employ IT4Sustainability?*	
MF6: SDEs employ digital technologies to tackle sustainability challenges on the company level (internal orientation; IT4S users)	• Practitioners should employ digital technologies to – professionalize the organizational culture, i.e., collaboration, – increase the product life of plants through timely maintenance, – achieve blended value propositions (environmental and social value).
MF7: SDEs employ digital technologies to tackle sustainability challenges of customers or whole sectors (external orientation; IT4S enablers)	• Governments, scholars, and practitioners should collaborate to create new IT4S visions, especially for traditional sectors with low digital maturity levels.

(continued)

Table 3 (continued)

Main Findings (MF)	Implications (for increased IT4S maturity)
	• Practitioners should question how they could promote socio-ecological transformations through increased digitalization for enhanced opportunity recognition. • Practitioners should develop a vision of becoming a sustainability/ IT4S enabler.
MF8: SDEs can achieve different maturity levels of IT4S.	• Practitioners should assess the IT4S maturity of their company to identify areas of improvement. • Governments/scholars should assess IT4S maturity of specific sectors or industries to develop targeted support systems and educational programs.

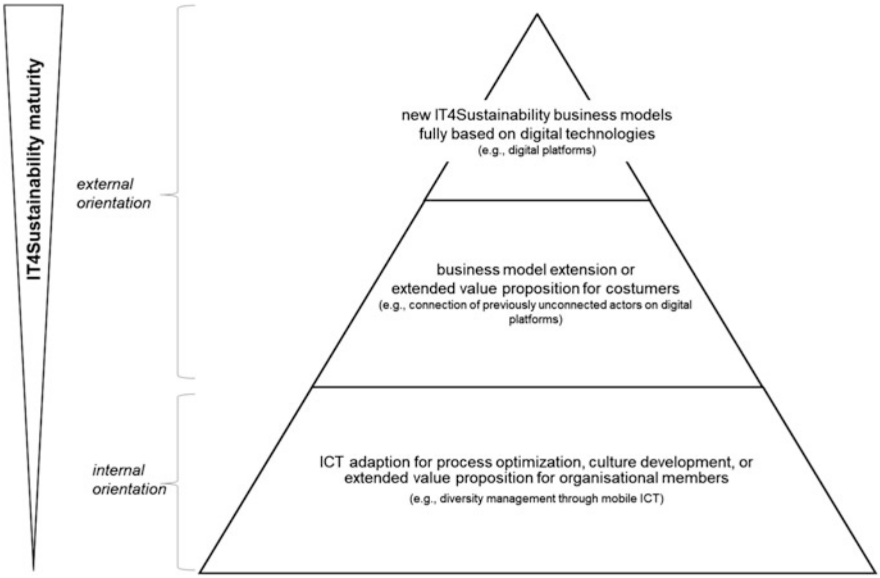

Fig. 1 Approach toward IT4Sustainability maturity in sustainable digital entrepreneurship (author's own)

development paths employed by such entrepreneurs were presented. Based on this, an IT4S maturity model was proposed.

Various theoretical, practical, and policy implications have been highlighted. For example, the identification of IT4S maturity levels (MF8) allows practitioners to assess the status of their company and identify areas of improvement. Overall, the rather diffuse understanding of the relationship between sustainability and digitalization (green digital orientation, MF5) calls for specific educational programs for (future) entrepreneurs and IS developers, including policy programs or innovation networks. Hackathons can enhance business-university collaboration (Happonen et al., 2020) and present a new learning environment for tackling societal challenges, such as the COVID-19 pandemic (Krüger & Teuteberg, 2020). For example, despite receiving innovation awards as a software developer for the car sector (digitalization enabler), there was no evidence that E4 developed a vision or joint purpose on how to use these digital transformation competencies to also leverage the sustainable transition of the car sector (IT4S enabler). Considering the IT4S development path and developing a Digital Corporate Digital Responsibility should become the new normal. Thereby, especially the information and communication sector should lead by example and act as an IT4S enabler for other sectors.

The limitations of this study reveal various research avenues. For example, further research is needed on the characteristics of SDEs in different sectors and effective training programs for (future) entrepreneurs. Similarly, in-depth investigations of IT4S development paths in specific sectors are needed (What are the potentials and limits? What are key enabling technologies?). Moreover, research should investigate the role of particular digital technologies and their functions, such as gamification, choice architecture, or digital nudging, to professionalize the sustainability-oriented organizational culture.

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Part III
Digital Transformation for Sustainability in Smart Cities

ECOSense and Sniffer Bike: European Bike Sensor Applications and Its Potential to Support the Decision-Making Process in Cycling Promotion

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Abstract Different bicycle sensor approaches in Europe have improved the existing bicycle database. The question is how and to what degree the results of these projects can be compared. The basis for this discussion are the projects ECOSense (Germany) and Sniffer Bike (Netherlands). ECOSense targeted the question of how to detect the state of the bicycle infrastructure, Sniffer Bike is aiming at providing new knowledge about critical air qualities that endangers cyclists' health. The paper provides discussion and evaluation of applied methodologies within the projects (e.g., sensor systems, citizen involvement). Results of the degree of citizen involvement and related data analysis parts will be presented. It will be discussed to what extent these findings are compatible and comparable. Data comparison parameters (e.g., number, durations, distances of bike trips, weather influence) and further related Key Performance Indicators (KPIs) are identified and presented. Limits of compatibility and comparability of the collected data are discussed. The conclusion shows strategies how stabilize the presented German and Dutch applications beyond the lifetime of the related research projects. Recommendations for future cross border data measurements to increase data quality and comparability are deduced.

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1 Introduction

Cycling has a lot of advantages for the environment, health, and well-being. Henriksen and van Gijswijk pointed out 10 key arguments that make cycling valuable (Henriksen & van Gijlswijk, 2010). One important aspect is inner-city air quality: The concentration of atmospheric aerosol particles or particulate matter (PM) is dependent on the fuels used by the vehicles as well as on the vehicle itself. Intensive vehicle utilization contributes to more PM that leads to smog formation. Smog could cause acute respiratory complaints. It is unclear to what extent cyclists are exposed to bad air quality and how the quality of the bike infrastructure effects the decision to use the bicycle. Another aspect pointed out in the work (Henriksen & van Gijlswijk, 2010) is the availability of a proper bicycle infrastructure. For instance, the Netherlands, the world leading bicycle culture, has built up an established bicycle infrastructure which makes it easier for a person to replace a vehicle with a bicycle, at least for short and ad-hoc rides (Henriksen & van Gijlswijk, 2010). Cycling promotion is valuable for municipalities from the financial perspective: Gössling et al. present a calculation of external and private costs for mobility in the European Union (Gössling et al., 2019). According to this study 1 km driven by car in the EU costs around 0.11€, while cycling on the same distance leads to monetary savings of around 0.18€. In relation to the total amount of passenger kilometers per year, usage of a car reaches up to 500 billion € annually, cycling brings a benefit of 24 billion € annually in the European Union (Gössling et al., 2019).

The availability of cycling data could help to learn more about needs of cyclists regarding the bicycle infrastructure and to identify the most preferred routes or weaknesses of the bicycle path network (Tošić, 2020). Compared to other modes of transportation (e.g., the automobile sector), the availability of cycling data is still relatively small, but continuously increases as part of different European and local initiatives such as *GovData,*[1] the *mCLOUD,*[2] the *CyclingDataHub* (CDH),[3] *Smart Zwolle Hub,*[4] the *dataplatform.nl,*[5] the *Dutch National Road Traffic Data Portal NDW,*[6] or the *Dutch government's National Data Portal.*[7] As a first step, many cities and regions already have applied smartphone mobile applications such as *Bike*

[1] https://www.govdata.de/.

[2] www.mcloud.de.

[3] www.cylingdatahub.eu.

[4] https://smart-zwolle.opendata.arcgis.com/.

[5] https://www.dataplatform.nl.

[6] https://ndw.nu/.

[7] data.overheid.nl.

Citizens,[8] *"Fietsmaatjes",*[9] the *"IkFiets"*[10] cycling promotion campaign or the *Bike counting week* in the Netherlands (*Fietstelweek*)[11] (Nationaler Radverkehrsplan NRVP (National Cycling Plan), 2017). The generated data provides a first overview of the general cycling behavior in a city [e.g., heat maps]. Nonetheless, one of the main functions of smartphone apps like *komoot* or *Garmin edge explore* (GPS tools for cyclists) is to navigate on recreational bicycle trips and bike tours (Froitzheim, 2020). These tools are often used by sportive cyclists to monitor personal training progress or used by very enthusiastic cyclists (e.g., ADFC members). According to a market analysis by the German Bicycle Club (ADFC) (Froitzheim, 2020) *komoot* is the most widely used application for bike tours. Because this type of the applications is considering only particular types of cyclists (e.g., sportive cycling), it is difficult to draw conclusions for further types of cyclists. It can be assumed that the existing data of bicycle apps is not representative for all types of cyclists and does only represent a very specific type of cyclists (Garbera et al., 2019). This could mean that the data based on bicycle apps is maybe not representative in terms of factors as selected routes, average speeds, or average durations.

To address this problem multiple bike sensor projects were conducted in different European countries. The bike sensor approaches conducted in these projects already made a huge amount of European cycling data available. For instance, it was possible to demonstrate that new target groups (e.g., elderly people) could be attracted. The question is how and to what degree the results of these projects with different sensor systems can be combined and compared. In this context, two national level research projects from the EU—ECOSense[12] (Germany) and Sniffer Bike[13] (Netherlands)—have developed and applied different sensor platforms to gather citizen cycling data. This paper presents and discusses the results of these research projects. Besides that, the paper provides discussion and evaluation of applied methodologies within the projects (e.g., sensor systems, citizen involvement) and additionally presents results of the data analysis parts. The layout of the sensor systems as well as the degree of citizen involvement (e.g., number of participants, age distribution) is shown and discussed. Data comparison parameters (e.g., number, duration, and distances of the bike trips, weather influence) and further related Key Performance Indicators (KPIs) are identified and presented in this work. Limits of compatibility and comparability of the collected data are discussed. The conclusion presents further bike sensor approaches and strategies, which show how the presented applications from Germany and the Netherlands can be applied to real-life scenarios and how utilization of the projects outcomes can go

[8] https://www.bikecitizens.net.

[9] https://www.regiozwollemobiel.nl/fietsmaatjes/.

[10] http://www.ikfiets.nl.

[11] https://fietstelweek.nl/.

[12] https://ecosense.mein-dienstrad.de/.

[13] https://civity.nl/en/products-solutions/sniffer-bike/.

Fig. 1 Sensor unit developed by CoSynth used in the ECOSense project. Source: University of Oldenburg

beyond the lifetime of the related research projects. Recommendations for future cross border data measurements are deduced.

2 The ECOSense Project

ECOSense contributed to the improvement of the available cycling database by a new bike sensor approach, which is strongly embedded into the civil society by active citizen participation. Oldenburg based Internet of Things (IoT) company CoSynth developed and tested a new bike sensor platform that collects various parameters of sensor data (e.g., position, speed, acceleration in three axes that enables an interpretation of the vibration levels, environment). First preliminary results of the project were published in the work by Schering et al. (2020). This paper gives a short overview about the sensor development, how the project was conducted and how vibrations or brakings can be detected. Figure 1 shows one of the sensor boxes that were supplied to more than 250 citizens in the Oldenburg area. 200 of these sensor boxes (including battery and housing), which can be mounted by hook-and-loop mounting strips to the bicycle in diverse positions (e.g., saddle tube, behind wheel) were produced. The newly generated and refined data sets lead to an improved information base about bicycle use in the daily life of citizens (e.g., commuting to work or place of education) and the state of the bicycle infrastructure. The implementation of the measurement technology enables decision-makers from municipal and traffic planning authorities to understand specific needs of cyclists better and enables the adjustment of bicycle infrastructures to specific demands of various types of cyclists. To support this process the anonymized, preprocessed, and refined data sets were published as open data at the mCLOUD.[14] The feasibility study was running for 15 months from June 2019 until the end of August 2020.

[14] https://www.mcloud.de/web/guest/suche/-/results/suche/relevance/ecosense/0.

Cycling is traditionally an important means of transport in the city of Oldenburg in Northwestern Germany and has a high priority. More than 43% of all trips within the city area are covered by bike (Arbeitsgemeinschaft Fahrradfreundlicher Kommunen Niedersachsen/Bremen, 2015). This special mobility culture shapes not only the inner-city traffic, but also the appearance of the city. Oldenburg has received several awards, most recently as the "bicycle-friendly municipality of Lower Saxony 2017–2021" (Arbeitsgemeinschaft Fahrradfreundlicher Kommunen Niedersachsen/Bremen, 2015). The high proportion of bicycle traffic has to be secured and expanded. The city is in the process of preparing a new "Master Plan Mobility and Transport 2025." For this purpose, comprehensive bicycle data should be collected and analyzed including active participation of the society in order to create a strategic and conceptual basis for cycling policy. Therefore, the ECOSense project fitted well to the strategic plans of the city to enhance its bicycle infrastructure.

2.1 Sensor Technology

The development of a new bike sensor platform that is attached to the frame of different types of bicycles was one of the key objectives of the ECOSense project. The sensor generated new data during bicycle use and supposed to help to understand the state of the infrastructure based on the generated data which was not available so far. CoSynth was responsible for the development of the sensor that records traveled distances, acceleration, vibrations, and various environment related data as humidity, air pressure, or temperature. Due to budget and time limitations, some of the original ideas were not integrated into the final design of the sensor and left out as outlook for further research projects (e.g., real-time analysis). Different as the Sniffer Bike environmental sensor application, NO_x and fine particle sensors are not part of the data collection because of the monetary costs and high energy demand. Following sensor parameters are part of the final sensor platform:

- The GPS is essential to locate the route selection and to detect the speed level
- Orientation and acceleration sensor provide information about the roughness of the bike paths
- Air pressure and temperature are gathered by the sensor to determine the environmental factors influencing cycling behavior.

As this sensor approach is strongly depending on active citizen participation, an involvement of cyclists is an important prerequisite. In order to facilitate smooth experience during the usage of the sensor, an easy and user-centric user experience had to be provided. For instance, there were no demands for recharging the battery during the participation phase or the data transmission. The battery has a usage period of roundabout 2 months, before a next recharging routine need to be performed. To safe energy, the sensor was only active during cycling movements. When the bicycle is parked the sensor fells into the "sleep mode." In the current development stage the data transmission process is based on the integrated SD cards without any real-time data transfer. That means that the cycling data initially is stored encrypted on the SD card. These SD cards were later provided to the data analysis team at the University of Oldenburg for further processing. By design the sensor is not connected to any external facility, which means that no external access (e.g., via Wi-Fi) is possible. Later, all generated data sets were transferred from the SD cards to a database for further data analysis at the university servers.

2.2 Citizen Participation

The project has proven that there is a huge interest by the general public to participate in *citizen science*-driven innovation processes. The lead partner meindienstrad.de (baron mobility service GmbH) organized the call for participants in the Oldenburg area and distributed the sensors to the general public. More than 500 people registered for participation within a very short time. Male cyclists are slightly overrepresented (59% male, 41% female). Compared to bicycle apps such as Strava[15] which tend to be used by experienced, frequent, and enthusiastic cyclists (Garbera et al., 2019) especially elderly people are strongly attracted to participate in the ECOSense sensor approach. More than 8% of the participants are older than 66 years and nearly 50% of the people are older than 46 years. That means that the share of people older than 66 years is higher compared to the share of young adults (18–25 years). Seniors are better represented compared to the younger generation (see Fig. 2).

2.3 Results of the Data Analysis (ECOSense)

In a first step, bike sensor data can be used to get an overview when exactly people are cycling in a city (e.g., to validate the measurements of local bicycle counting stations). To learn more on the matter, all bicycle trips were visualized according to the starting times. The aggregated bicycle trips were used for this kind of visualization. The visualization in Fig. 3 (left) shows that there are peaks in the morning and the afternoon. In general, it could be assumed that a high share of bicycle trips is performed on the way to work (morning, afternoon) or to school (morning, noon). Although these peaks are not clear outliers, as it would be expected, but these could be clearly spotted on the plotted diagram. Surprisingly, there is also a peak in the very early morning around 4 a.m. It has to be mentioned that a huge part of the data collection took place during the first Corona lockdowns in the EU. Thus, mobility was very limited between spring and summer 2020 (see for details Fig. 5 below).

[15] https://www.strava.com/.

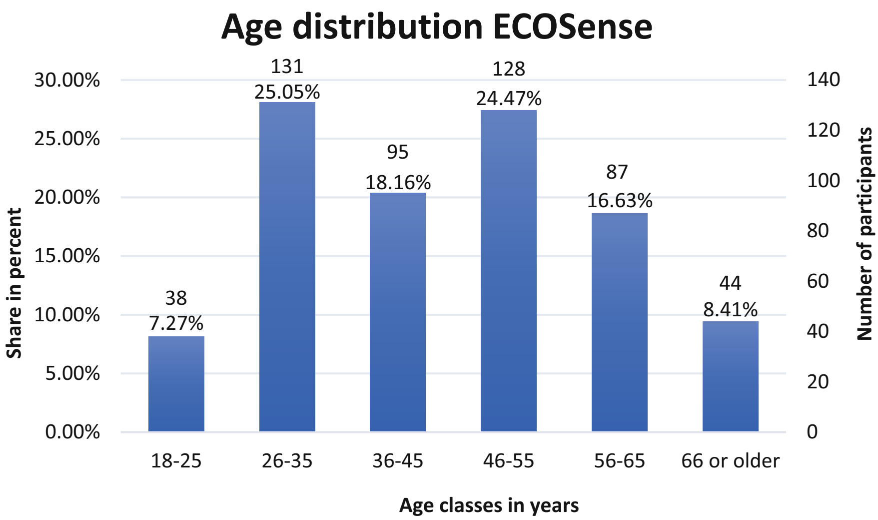

Fig. 2 Age distribution of the participants (ECOSense)

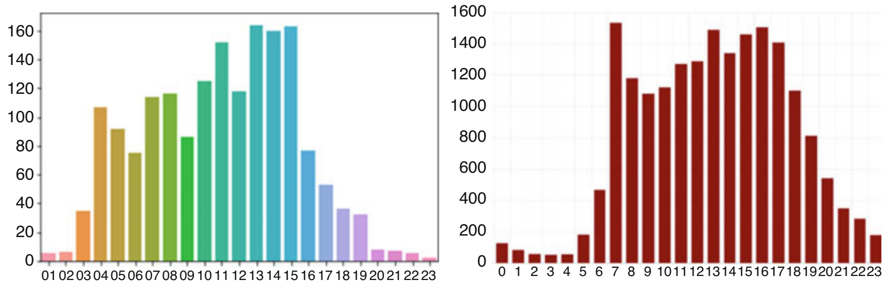

Fig. 3 Hourly values (ECOSense, left), bicycle countings (city of Oldenburg, right)

To validate the reliability of the hourly distribution, these could be set in a proportion with the measurements of the 14 bicycle counting stations in the city area of Oldenburg. This data shows a similar pattern, but there are also some deviations. Figure 3 (right) shows the hourly averages per day between November 2019 and July 2020 during the data collection in the ECOSense project. There is a peak in the morning, around noon and in the afternoon. Nonetheless, the bicycle counting stations show a much higher peak in the morning between 7 and 8 a.m. (and no morning peak at 4 a.m.). According to the data from the bicycle counting stations, the peak in the afternoon occurs slightly later compared to ECOSense around 4 and 5 p.m.

The next step of the data analysis was the interpretation of the bicycle trips regarding the route selection and the average speed levels. The dataset was analyzed in order to understand which exact connections are preferred by cyclists and whether connections or hubs with increased or decreased speed levels could be identified.

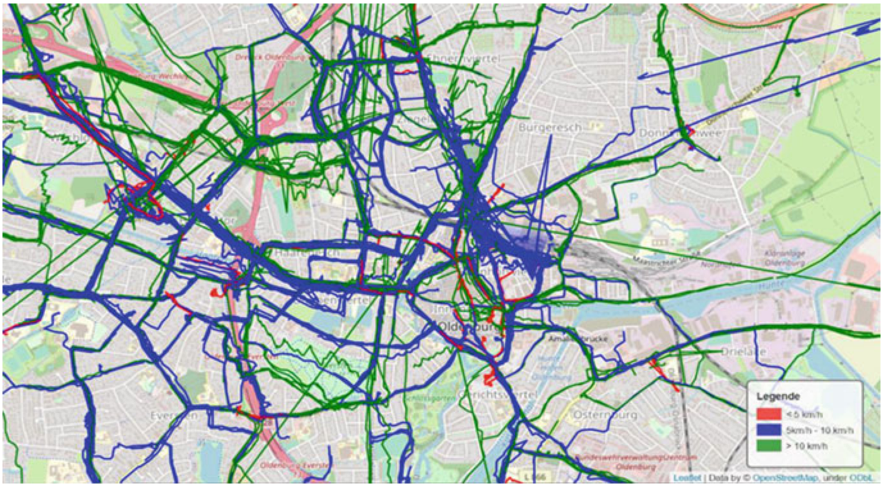

Fig. 4 Heatmap of bicycle trips and average speed levels in Oldenburg

The results of 1.196 bicycle trips are presented in Fig. 4. Very low speed levels below 5 km/h are represented in red, middle speed level between 5 and 10 km/h in blue, and high speed levels above 10 km/h in green. The main finding is that cyclists tend to prefer cycling on main roads of the city (e.g., Ofener Straße, Ammerländer Heerstraße or Alexanderstraße in Oldenburg). The visualization makes clear that the speed levels at the main roads are lower compared to the secondary connections. It can be assumed that cyclists need to brake more often at the main roads because of intersections, traffic lights, or other obstacles on the road which leads to a decrease of the cycling speed.

Cycling is usually strongly impacted by environmental conditions (Handy & Xing, 2011). Therefore, the weather influence on cycling behavior, namely distances, durations, and speed levels, was investigated. Under moderate and good weather conditions the average distance of an ECOSense trip is about 3.59 km and shows an average duration of about 17 min. If the weather conditions are bad before a trip starts, the average distance shortens up to 3 km and a duration of 15 min. Bad weather conditions have an impact on distances but not on speed levels. As Fig. 5 shows, there seems to be no correlation between the speed levels and differing levels of temperature and wind speeds or the amount of sunshine hours or precipitation. It will be later demonstrated that these findings can be confirmed by other sensors used in the Sniffer Bike project.

The acceleration data of the ECOSense sensor is collected 24 times per second (24 Hz), which allows precise data analysis regarding the state of roads or bike lanes. As we will see below, the Sniffer Bike sensor does not allow this kind of analysis, because of a much lower measurement frequency. The ECOSense bike sensor system detects the acceleration in the three directions (x,y,z). When a cyclist crosses a pothole or a (dropped) kerb a strong movement of the vertical axis can be

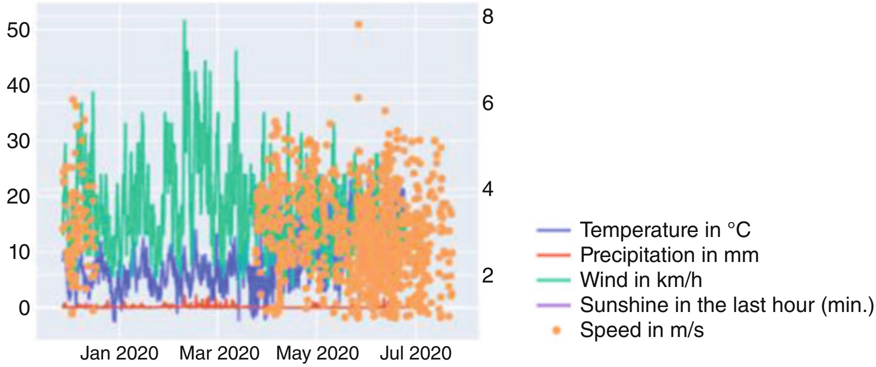

Fig. 5 Correlation between environmental factor and speed levels

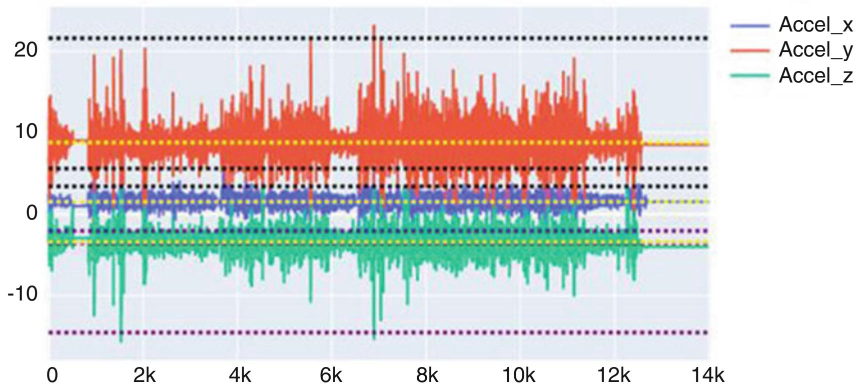

Fig. 6 Example of acceleration data during a bicycle trip

reorganized and recorded. It has to be mentioned at this point that, contrary to the Sniffer Bike project, the sensor was installed on a bicycle in different positions. Figure 6 shows an example how the acceleration data could look like. The visualization shows the values of the acceleration sensor (y axis) in m/s^2 which means a normal acceleration. The x axis shows the data points in a consistent time interval.

To identify the vibration level of a bicycle during a trip, a comprehensive preprocessing of the bike sensor acceleration data was necessary. An average acceleration level for all the three axes was calculated. This averaged value was defined as the degree of vibration on an average trip. This is necessary because there is no bicycle trip without any vibration—these are also detected when someone is cycling on a road with perfect road conditions. The vibrations need to be analyzed for every single trip, because every cyclist and every bicycle (e.g., suspension) is different. Such differences could have a significant influence on the measured values. The key target of the analysis was to identify outliers in form of sudden

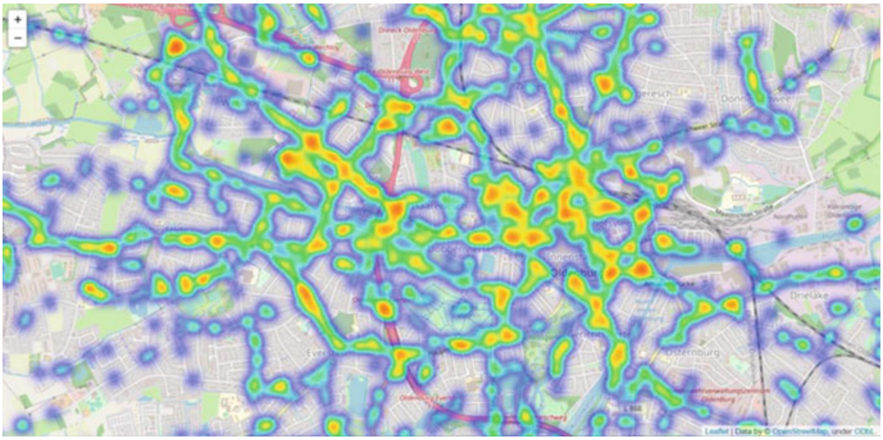

Fig. 7 Vibration heatmap of the road surfaces (Oldenburg area)

Fig. 8 Vibration of the road surfaces (Stau, Oldenburg)

changes in the data set. These outliers could be interpreted as markers on the road, kerbsides, or other disturbances and obstacles on the road surface. All outliers identified were visualized on a map. The interactive representation style was used to visualize aggregated number of outliers (not the same as the vibration degree) in the Oldenburg area (Fig. 7). At the provided level of detail it is not possible to argue about the surface quality of a certain road. However, it is easy to spot that there are many vibrations in the city center.

Many vibrations can be perceived at spots where participants of the project cycled the most, especially at the main roads of the city. Figure 8 shows a higher resolution level—a lot of vibrations were detected at intersections (traffic lights) or when the type of road surface is changing (e.g., from asphalt to cobblestone) because the cyclist need to cross a kerb side or edges, which in most cases results in a spike

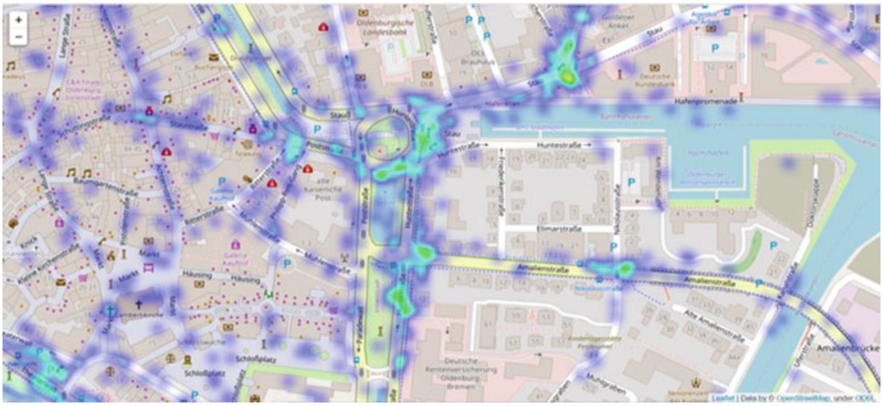

Fig. 9 Distribution of brakings in the inner city area (Stau, Oldenburg)

vibration measurement. However, it is not always possible to reason about an exact vibration level and the type of vibration, based only on obtained from the raw data results. It could be hard to clearly identify a specific type of vibration (e.g., crossing a gully cover, kerb or huge tree root) because the same spike-pattern could be initiated by various factors. Additionally, it is challenging to identify whether this situation belongs to a damage of a road surface or to a normal cycling situation without any disturbance (e.g., crossing a drop kerb). Follow-up research approaches could focus on a further investigation of the acceleration data to learn more about spots with a high vibration intensity in the traffic infrastructure. This could help to illuminate the so-called false positive spikes, which are represented by the crossing of kerb sides or a new non-typical type of road surface. The perspective of the cyclists could be reconsidered (e.g., by surveys, interactive user feedback based on the sensor data). There are already answers available on parts of these technical questions: As part of another study, Zang et al. (2018) successfully developed and applied algorithms to measure the surface roughness of roads to identify potholes and humps on these roads and bike paths based on acceleration data of smartphones, which were mounted on the bicycles. Vanwalleghem et al. (2013) showed that it is possible to detect surface types as cobblestone as part of vibrational comfort evaluation not only in laboratory experiments, but also in field tests. The acceleration sensors were installed on the saddle and the handlebar (Vanwalleghem et al., 2013).

To gather new knowledge about the braking behavior of cyclists, the speed levels and changes of these were further investigated. A braking can be defined as a sudden decrease of the speed level of the cyclist. A sliding window approach (Tangwongsan et al., 2015) was applied to investigate a defined time interval on the whole bicycle trip. Every trip was divided into very short subsets to identify sudden changes of the speed level, which could be then interpreted as “braking” events. As the speed level of a cyclist during a trip varies, the threshold value was defined as 0.7. It means that a braking is happening when a decrease of the speed level of more than 30% in the sliding window is perceived. The braking events were visualized on a marker map and a heatmap (Fig. 9). Very similar to the vibration data, many braking events can be perceived at intersections as well as traffic lights. In comparison with the vibrations, the braking events are less concentrated to junctions but more distributed to the whole city area. Many braking events can be spotted at bicycle stops, parking facilities, or shopping areas.

3 The Sniffer Bike Project

A project very similar to the ECOSense approach is the Sniffer Bike project which was started in May 2019 in the Province of Utrecht, Netherlands. The bicycle sensor based project has also a strong focus on the active involvement of cycling citizens and citizen science approaches to make new cycling data available. Sniffer Bike or *Snuffelfiets* is characterized by the active involvement of citizens in the form of collecting and exchanging bicycle sensor data. Benefits of projects as ECOSense or Sniffer Bike are that these can help to pinpoint local problems better, create more understanding of the current needs, and better predict future mobility behavior (Booth & Richardson, 2001). Moreover, actively involving citizens results in raising awareness amongst citizens, can initiate (or improve) the dialogue on the subject, and increase the exchange of data (Kobernus et al., 2013). The sensor configuration on the 550 produced Sniffer Bike sensors not only recording the GPS positions, the acceleration, and the speed level, but also a large amount of environmentally relevant data (including fine particles PM2.5, temperature, humidity). Compared to ECOSense, a stronger focus on air quality measurements can be perceived. The raw data is published on a daily basis on the Dutch website dataplatform.nl.[16]

Utrecht, a historical city centrally located in the Netherlands close to Amsterdam, is famous for giving space to cyclists and pedestrians. Although space is limited, Utrecht has created one of the best bicycle infrastructures not only in Europe but even compared to other places in the Netherlands in terms of consistency, directness, attractiveness, safety, comfort, spatial integration, experience, and social economic value. In 2014, more than 44% of the population were cycling (Hull & O'Holleran, 2014). The motivation of the Province of Utrecht to start the Sniffer Bike project is to stay one of the most competitive regions in Europe. The development to a healthier region with optimal living and working climate is an important part of this long-term perspective. The Sniffer Bike project is an attempt to learn more about the air quality as well as the cycling behavior. The general public participates in this process by the data distribution. The interaction and communication with the society is improved. The data is also being used by the Province of Utrecht for the analysis of route choice and delays at traffic lights.

The city of Zwolle which is the capital of the Province of Overijssel and located close to the Ijsselmeer is also part of the Sniffer Bike project. Zwolle is seeking for information on the particulate matter levels, durations, speed, and delays during bike

[16] https://dataplatform.nl/#/data/9cc4de28-6d03-4b59-8c66-085b3e8b3956.

trips to optimize future policies on bicycle mobility. In this context, the Sniffer Bike data gives new input to increase comfort, speed, and safety for cyclists. Sniffer Bike in Zwolle is part of an ambitious mobility plan to raise the amount of bicycle trips by 20% in the next 10 years. Before the implementation of Sniffer Bike, the municipality of Zwolle used different methods to gain insights in bike use and air quality levels. Bicycle use is measured in two ways. The first one is ODiN & OViN, a national research from CBS ("central office of statistical analysis") based on surveys (e.g., questions about transport motives at a particular day). The second one is the bicycle count week (*Fietstelweek*) which counts bicycle use for 1 week in the whole Netherlands. Air quality is measured by the NSL monitor tool (*Nationaal Samenwerkingsprogramma Luchtkwaliteit*, National Air Quality Cooperation Program).[17] Once a year, this tool measures the air quality (PM10, PM2.5, and CO_2), based on parameters as traffic or buildings. The outcome gives an accurate estimate for air quality levels. In the municipality of Zwolle, the air quality will be measured by the NSL tool at least until the end of 2021.

Sniffer Bike is part of the EU funded project BITS (Bicycles and Intelligent Transport Systems,[18] program Interreg B). One of the key objectives of BITS is to make cycling data from European countries available in a harmonized structure and a comparable format. To enable interested stakeholders to share bicycle data sets, an open data platform, the so-called *CyclingDataHub* (CDH), is implemented and hosted by the Province of Antwerp (Belgium). The platform provides an open access to external datasets relating to *smart cycling* applications as bike counters, sensor data (e.g., Sniffer Bike, ECOSense), or near accidents. The objective is to improve the availability of cycling data by external stakeholders as municipalities, businesses, and researchers working on data-driven cycling solutions. The external partners have also the opportunity to contribute to the CDH by supplying their data sets. The digital platform as a result of the BITS project should be a step forward to a common understanding of cycling data and makes *smart cycling* more visible in the European context.

3.1 Sensor Technology

Sniffer Bike is based on the so-called Particulate Matter Sensor SPS30 by Sensirion.[19] The MCERTS-certified SPS30 particulate matter (PM) sensor is applying laser scattering to determine the size and amount of the fine particles in the air. The manufacturer promises a lifetime of the sensor which is presented in Fig. 10 of more than 10 years. Particulate matter with particle diameter up to 2.5 μm (PM2.5) belongs to the most dangerous air pollutants. Because of its small size, PM2.5

[17] https://www.nsl-monitoring.nl/.

[18] https://northsearegion.eu/bits.

[19] https://www.sensirion.com/en/environmental-sensors/particulate-matter-sensors-pm25/.

Fig. 10 Sensor unit used in the Sniffer Bike project. Source: Province of Utrecht

particles can move up deeply into the lungs which can lead to many health issues as asthma (Thompson, 2018), cardiovascular disease (Pope et al., 2018), or autism (Volk et al., 2013). In contrast to the ECOSense approach, the sensors are standardized attached between the bicycle handle and central bar. The data is transmitted in near real time via the mobile phone network. More than 550 sensors are supplied to the citizens at various locations in the Netherlands (including Utrecht, Zwolle, 's-Hertogenbosch, Zeeland) and even in other European countries (e.g., in Denmark, Sweden).

Further studies tested the feasibility of the air quality measurement based on mobile bike sensors. Bertero et al. (2020) conducted successfully a study with state-of-the-art sensors to detect NO_2 concentrations in the city of Marseille, France, with a small fleet of less than hundred bicycles. Low-cost sensors can lead to uncertainties in terms of data quality (Bertero et al., 2020). Shen et al. (2019) presented a study based on a sensor detecting particles, temperature, humidity including SD card, GPS receiver, and an NB-IoT communication module. The PM2.5/PM10 laser sensor which was tested in a Chinese bike sharing system can obtain 0.3–10 μ suspended particulate matter concentration in the air and, according to the authors, delivers data of high quality (Shen et al., 2019).

3.2 Citizen Participation

According to the Province of Utrecht demographic information about the participants was not recorded in detail because of privacy concerns and the focus on other aspects of the data. But, confirming the results of ECOSense, a high motivation for elderly people to participate was perceived. Many middle- and higher-aged cyclists were involved in exchange formats or have contacted the project by email. Many less tech-savvy people showed interest to be an active part of the project. Sniffer Bike offers a good example of how the bike trips of the cyclists can be made freely available for the general public as open bicycle data over a longer period of time. On the one hand, the anonymized raw data of the most recent bicycle trips is published weekly in a Dutch open data portal. On the other hand, the current routes, including information on air quality, are visualized on a daily basis on a publicly accessible interactive dashboard.[20] On a personalized website with individual log-in the participants may find their personal bicycle trips and relating statistics.

The data collection in the Province started in May 2019 and was supposed to run until the start of Vuelta a España[21] in Utrecht in August 2020 (Hitman & Hanenbergh, 2020). Because of the Corona crisis the event was canceled and the data collection period was extended until the end of January 2021. About 500 volunteers in the Province of Utrecht and 50 volunteers in the neighboring Province of Gelderland attached the device on their bicycles to collect environmental and bicycle data. In order to validate the sensor data, RIVM (*Rijksinstituut voor Volksgezondheid en Milieu*, Netherlands National Institute for Public Health and the Environment) developed a validation process based on co-located Sensirion SPSP30s at three (static) national air quality measurement network sites. The key results of the Sniffer Bike project have been evaluated on the 23rd of January 2021. During an online event the Province of Utrecht announced that the community-based approach will be continued as part of a community-based *Citizen Science* program (de Haas & Hamersma, 2020). This is contrary to the Province of Gelderland. The key difference between the two provinces is the number of volunteers and the amount of data generated. It can be concluded that it is essential to have a critical mass to reach relevant results.

Sniffer Bike devices have also been deployed in the city of Zwolle which published a call for participation with special focus on frequent bicycle users. The bike sensors became a part of the Senshagen project[22] that focused on obtaining insight in climate and participating with the citizens of the neighborhood of Stadthagen by collecting sensor data. The citizens of Zwolle showed high interest in participating in the Sniffer Bike initiative. The project has started on the 4th December 2019 with a participants evening where the sensors were handed out to the participants. Ten regular cyclists between 25 and 55 years adopted a sensor on their bike and started making measurements with every trip they make. The motivation of the city administration to be part of the project is to gather new information about particulate matter levels, length of trips, speed during the trips, and delays on routes. For the initial goal to obtain more insight in air quality on frequently used bike lanes, there are more bike sensors needed to draw conclusions. In contrast to the Province of Gelderland, the city of Zwolle is planning to scale up the Sniffer Bike project 2021 as part of the BITS initiative. The goal is to supply between 100 and 250 sensors to interested cyclists in and around Zwolle to different target groups as bike couriers, company bikes, members of the local cyclist federation or school pupils.

[20] https://dashboard.dataplatform.nl/sodaq/v2/groene_fietsroutes.html.

[21] It is intended to reorganize the event in Utrecht in 2022. Utrecht will be then the first city in the world that has hosted all three major cycling races (beyond the Giro d'Italia 2010 and the Torur de France in 2010). The trip at the Vuelta a España should be a ride about 24 km, starting from Jaarbeurs trade and conference venues crossing through working class districts, the suburbs, the shopping center, and the University. The cyclists will enter the Province at Rhenen and are crossing the Heuvelrug National Park. See Hitman and Hanenbergh, pp. 74 and 124.

[22] https://senshagen-zwolle.opendata.arcgis.com/.

Fig. 11 Heatmap of bicycle trips in the Netherlands (ArcGIS, copyright by Esri)

3.3 Results of the Data Analysis (Sniffer Bike)

As part of the EU project BITS, the business informatics department VLBA of the University of Oldenburg prepared and evaluated the data records of the Sniffer Bike project. During the first 10 months of the project, more than 100.000 data points in the Netherlands were recorded. About 62.336 trips with an average distance of around 7 km and an average duration of 35:45 min per trip with an average speed level of 13.79 km/h were measured in the regions of Utrecht and Zwolle between May 2019 and end of March 2021. The average distances and travel times per trip are longer compared to ECOSense, which indicates differences in the measurement technology used. Figure 11 shows a heatmap of the bicycle trips in the Netherlands.

Similar to ECOSense, all Sniffer Bike trips were visualized according to the starting time of the bicycle trips (time stamp). The visualization in Fig. 12 shows clear peaks in the morning and the afternoon. A high share of bicycle trips when commuting to work or school can be assumed. It can be concluded that the bicycle is strongly used in daily life in the Netherlands. It has to be mentioned at this point that the Corona virus has changed cycling behavior: It seems to be that recreational bicycle use has increased a lot. Figure 13 shows the starting times of the bicycle trips (time stamp) between March and June 2020. The morning peak is much less remarkable instead of a peak that durates the whole afternoon from 3 to 6 p.m. It can be concluded that the bicycle is more used during leisure time in the Netherlands than before. This is also proven by a look to the average distances and durations (Fig. 14) that show a remarkable increase in spring 2020. The citizens stayed at home for home office or schooling and used their bicycles more during leisure time compared to commuting to the working or education place. Although the behavior

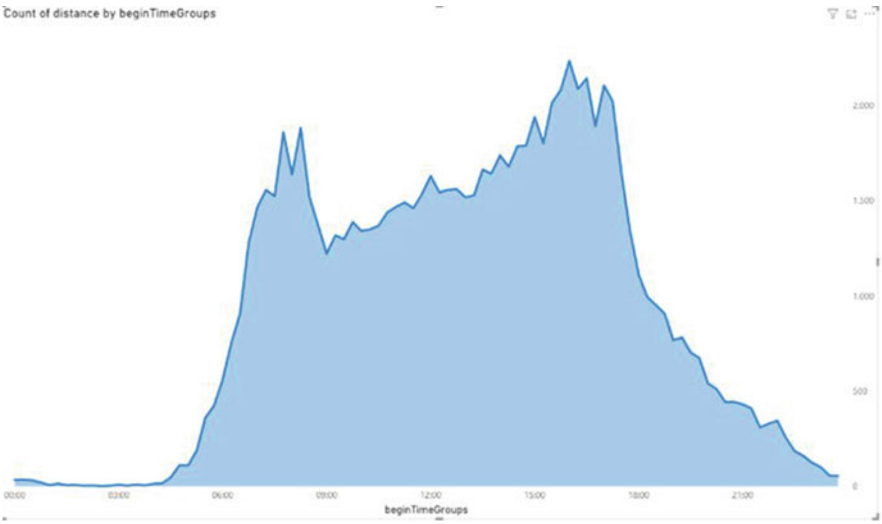

Fig. 12 Hourly values (Sniffer Bike, MS Power BI)

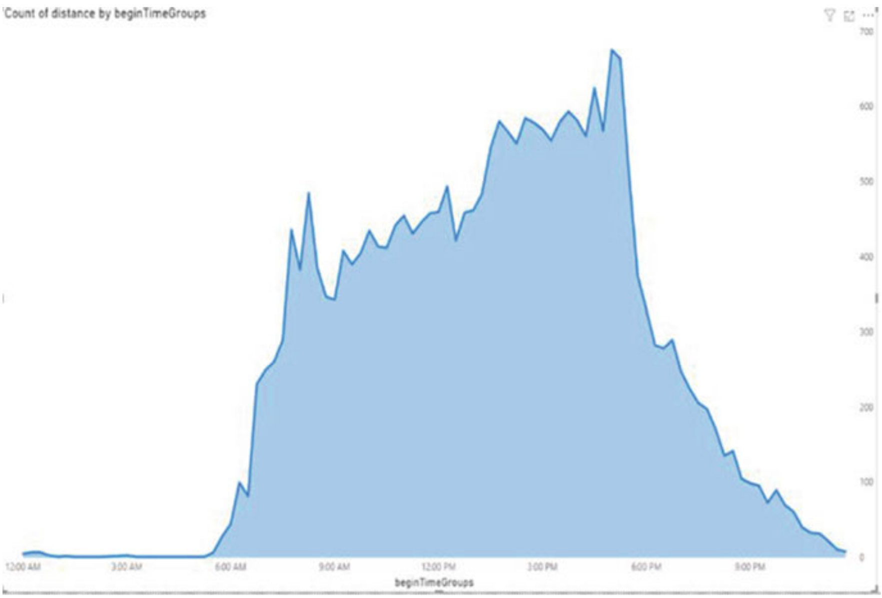

Fig. 13 Hourly values spring 2020 (Sniffer Bike, MS Power BI)

of the cyclists has changed, according to other publications, the total bicycle use in the Netherlands remained stable during the Corona crisis (Schouwenaar, 2021).

Part of the Sniffer Bike data analysis was also the observation of the weather influence on cycling behavior, namely distances, durations, and speed levels. Many

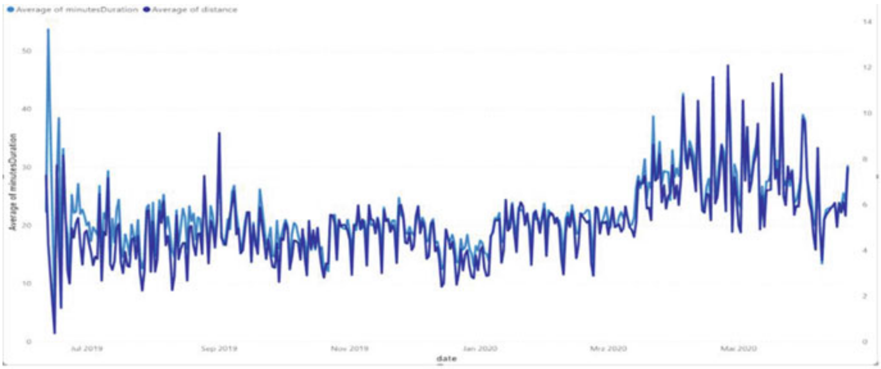

Fig. 14 Average distances and durations of bicycle trips in the Netherlands (MS Power BI)

Table 1 Weather influence on durations, distances, and speed levels (Province of Utrecht)

Weather classification	Count	Average distance (km)	Average cyclist speed (km/h)	Average duration
Cold	23,026	6.56	14.28	00:30:22
Heavy rain	452	7.11	14.22	00:38:57
Heavy snow	79	8.12	15.71	00:36:50
Heavy summer rain	4	5.51	14.28	00:19:29
Hot	881	8.12	13.7	00:37:39
Hot humid	81	6.81	14.08	00:32:11
Humid	254	7.08	14.89	00:30:22
Light rain	6667	6.54	13.87	00:33:12
Light snow	100	7.45	16.04	00:30:55
Light summer rain	139	8.3	12.83	00:41:57
Moderate	15,583	7.24	13.64	00:37:32
Stormy	7	6.76	13.48	00:30:59
Warm	10,507	7.78	13.53	00:40:17
Windy	564	6.88	13.37	00:32:51

of the ECOSense findings can be confirmed. Under dry weather conditions (moderate) the average distance of a Sniffer Bike trip in the Province of Utrecht is about 7.24 km long and has a duration of about 37.5 min. If the weather conditions are bad when a trip starts the average distance shortens. This is the case for the classifications cold (6.5 km in 30 min), windy (6.8 km in 32 min), or light rain (6.5 km in 33 min). Surprisingly, under snowy weather conditions the distances are increasing (heavy snow 8.1 km in 36 min). Confirming the ECOSense results, bad weather conditions have an impact on distances but not on speed levels which lies between 13 and 14 km/h. The only exception are the snow classifications (heavy snow 15.7 km/h, light snow 16 km/h) which could be an outlier because of the limited number of trips (179). As Table 1 shows, there seems to be no correlation between the speed levels and differing weather conditions.

Fig. 15 Heatmap of fine particles in Zwolle (ArcGIS, copyright by Esri)

Because the Sniffer Bike sensor is gathering only one measurement in around 11 s it was not possible to conduct very specific data analysis regarding the state of the infrastructure (vibrations) or the brakings of the cyclists. Beyond the ECOSense approach, the Sniffer Bike sensor allows an observation of the air quality. Similar to the ECOSense results, intersections can be interpreted as problem points which tend to have a highly increased concentration of PM2.5 particles. In general, main roads show a much more problematic air quality compared to less frequented roads nearby. Industrious zones (e.g., Hanzeland in Zwolle) also show increased concentration of fine particles in the air which is visualized in Fig. 15.

The environmental data generated in the Province of Utrecht so far has been mostly used for monitoring purposes. The main reason is that measures to improve air quality take time to take effect. However, based on the detected bicycle trips, the Province was able to adjust the timings of the traffic lights at certain crossings to improve bicycle flow without significant disturbance for other modes of transport. Furthermore, the data is implemented in a “tunnel scan.” This tool finds possible, evidence-based, locations for the construction of bicycle tunnels or underpasses.

The unique aspect of Sniffer Bike is the combination of open source, open data, citizen science, and direct government use of data. Both the information needs of individuals, policy makers and society in general are fulfilled with one and the same data source. The Province of Utrecht provides an open data platform that is hard to maintain for individuals while individuals provide data that is difficult to gather for the Province.

4 Related Works, Conclusion, and Outlook

In addition to the two research projects described above in detail, digital business models have already been developed around the subject of bicycle sensors. A recently founded German start-up called Upride[23] which is based in Munich has developed another bike sensor application similar to the ECOSense approach. This sensor detects acceleration and geo data to identify road damages and potential problems of the bicycle infrastructure. In contrast to the ECOSense approach, the bicycle data is transferred in real time via a Bluetooth connection. The results are visualized for the respective customer, namely the municipalities, and documented in a report. Upride was awarded with the German National Mobility Award in 2020 (*Deutscher Mobilitätspreis*). As part of the competition, 10 Best Practice examples were selected out of more than 300 businesses, startups, research institutions, and associations (Bundesministerium für Digitales und Verkehr (German Federal Ministry of Transport and Digital Infrastructure BMDV), 2020). Differences between Upride and ECOSense need to be stated. During the first year of the data collection of Upride, 6.000 cycling kilometers of 30 participants in Munich were successfully recorded and processed. The sample of participants is much smaller compared to ECOSense and Sniffer Bike, the results may be less representative regarding bicycle use of the general public (Lang & Süddeutsche Zeitung, 2020). Another difference is that the Upride sensor is integrated into a device that should avoid bicycle theft. The user is notified when the bike is stolen and can look up the current bike location on a map (Lang & Süddeutsche Zeitung, 2020). That differs on the future development path of the ECOSense sensors. In the follow-up project INFRASense,[24] the sensor application will be expanded by a real-time data transmission and battery charging devices for the participants. The sensor system will be embedded into a software application that determines the quality levels of the bike paths based on the sensor data, the amount of (bicycle traffic), the wideness and the conditions of the bike paths, and other criteria. The measured qualities will be verified by user feedback on a website. Municipalities should be enabled to prioritize concrete measures in the bike infrastructure planning based not only on the sensor data but also on a holistic assessment methodology that includes the user perspective (Bundesministerium für Digitales und Verkehr (German Federal Ministry of Transport and Digital Infrastructure BMDV), 2021). More details on the project will be presented in further publications. In any case, the focus will not be on bicycle theft avoidance.

See.Sense[25] has an even closer eye on cyclists and their road safety on the individual trip. The company which is located in the capital of Northern Ireland, Belfast, sells a bicycle sensor that is integrated into a smart bicycle light. The light is mainly attached to the seat post or under the saddle. See.Sense is also available as a front light which is attached to the handlebar. According to the company website, the

[23] https://upride.io/.

[24] www.infrasense.de.

[25] https://seesense.cc/.

main target group are in particular commuters whose visibility (e.g., at intersections or bridges) and thus road safety on the route to work need to be improved. The brightness of the light can be adapted to the situation. According to See.Sense, the battery life is about 12 h, so that the commuter has to charge the sensor about once a week. The sensor detects data on route selection (GPS), acceleration, light levels, temperature, and other parameters. The data is transmitted every 5 min. On the basis of the bicycle data, very similar to ECOSense, new knowledge can be gathered about the state of the bicycle infrastructure (surfaces, braking behavior, etc.). Similar to Sniffer Bike, the users also have access to a smartphone application that delivers personal statistics (cycling distances, average speeds, etc.) as well as updates about the battery level. In addition, an alarm function is integrated to improve theft protection. In the past, See.Sense has carried out some projects with cities as Antwerp in Belgium or Dublin in Ireland. The See.Sense trackers are also an integrative part of the BITS project: Beginning from summer 2021, 50 bike lightning sensors are being deployed via East Riding of Yorkshire Council's bike library scheme in the coastal town of Withernsea, United Kingdom. As part of the BITS project extension, the ERYC team is also planning to deploy the sensors in four other bike libraries in the region (Candelari, 2021) in order to generate new and additional datasets for locations that are quite diverse in terms of geography and demographics. According to the See.Sense website, the sensor approach is valuable for traffic engineers, especially when it comes to prioritizing measures for the improvements of the bicycle infrastructure (quality levels are not provided). As already mentioned, See.Sense sets its focus on traffic safety and the cyclist herself/himself, especially on people commuting to work. The focus on commuters could maybe neglect the data collection of cyclists that are outside of this target group (e.g., elderly people that do not cycle to work, people that are mostly working from home). ECOSense and Sniffer Bike are targeting on a representative data collection which includes all types of people (including the elderly and other users that often were not monitored before by bicycle smartphone apps, see Fig. 2). The See.Sense tracker does not include air quality sensors (Sniffer Bike) but sensors on lightning conditions. The See.Sense application is not embedded in a software solution to enable a holistic assessment of the bicycle infrastructure (ECOSense and INFRASense) as it is mainly limited to cycling behavior, the vibrations that occurring on the bike trip and the lightning conditions.

In terms of traffic safety, other approaches of bike sensors focused on detecting the spatial environment of cyclists. Lee et al. implemented a sensor system based on two laser scanners installed at the front side of the bicycle and two cameras of wide view angle to detect changes in the surrounding area (e.g., by pedestrians or vehicles). The motion of the cyclists was also detected by body sensors (Lee et al., 2014). The Technical University of Kaiserslautern presented a connected bicycle concept at the Eurobike 2018. Beyond GPS and acceleration sensors, the bicycle integrates a lidar sensor at the handlebar to detect dangerous situations and vehicles on the front side. Before a dangerous situation occurs, the cyclist is warned by haptic (vibration of the handlebar) or audio (sound) signals (Mellinger, 2018). The project Kaiserslautern is strongly targeting on the development of riding assistance systems to avoid bicycle accidents or at least critical situations. As part of the project, smart lighting and warning systems to avoid frontal or backside collisions and lane departure based on bike sensor systems were tested and evaluated. Sniffer Bike and ECOSense do not have a strong emphasis on cycling safety and do not provide safety relating riding assistance systems. Cycling behavior and conditions are monitored as part of a crowdsourcing approach instead. Based on the data that is gathered by real cyclists in Sniffer Bike and ECOSense, decision making in the cycling promotion process and the related bicycle safety situation can be improved.

The Karlsruhe University of Applied Sciences is also working on a so-called EcoSensorBike which shows similarities to the ECOSense approach. The feasibility of many bike sensors as temperature, wind speed, noise, environmental emissions, side distance when overtaking, brakings or surface quality was tested and evaluated (Nationaler Radverkehrsplan NRVP (National Cycling Plan), 2019). According to Martin Temmen, research associate at the endowment chair for cycling studies, the department has four sensor bikes available at this moment (two trekking bikes, one pedelec, one e-cargo bike). The development of the sensor bikes was realized as part of several student projects. ECOSense and Sniffer Bike follow a strong crowdsourcing-based approach as several hundreds of local citizens participated in the data collection. In the Karlsruhe case, investigations on a smaller scale were realized in the inner city traffic regarding factors that may influence cycling behavior and connections of these. Beyond the sensor data of the bikes, several health parameters of the cyclists were also part of the data collection (e.g., heart beat rate, stress level).

ECOSense and Sniffer Bike show many similarities and parallels. The citizens in Oldenburg, Utrecht, and Zwolle showed high interest and active participation in the projects. Many elderly people took part in the data collection. The hourly values reveal that many people are using their bikes on their daily trips to work or the place of education. As we can see there seems to be a clear shift to recreational bicycle use in spring 2020 because of home office and lockdown consequences. Both approaches confirm that there is an influence of the weather conditions to the cycling distances and durations. Especially under cold, rainy, and windy conditions the trips tend to be shorter. The speed levels of the cyclists are not or only a little bit affected by different weather conditions. It was not possible to directly compare the average cycling distances in Oldenburg with the Province of Utrecht, because different sensor systems were used. The Sniffer Bike sensor shows longer average distances, but it cannot be concluded that bicycle trips in the Netherlands are longer in general. Due to the higher accuracy of the measurements (e.g., 24 Hz), the ECOSense approach allows conclusions on the state of the bike infrastructure (vibration, braking events). However, the project Sniffer Bike allows a more detailed investigation of the air quality and potential health risks for cyclists in cities based on the integrated PM2.5 sensor.

Table 2 gives a detailed overview about the potential parameters of both projects ECOSense and Sniffer Bike that were discussed in this publication in terms of comparability.

Table 2 Comparative parameters of ECOSense and Sniffer Bike

	ECOSense	Sniffer bike
Age structure	Nearly 50% of the participants are older than 46 years	No statistics about the age structure were collected, but the citizen participation events showed a similar picture: Many elderly and less tech-savvy people were engaged in the project
Number of sensors	200	550 (will be expanded)
Position of the sensors	Different positions (saddle tube, back wheel, etc.)	Standardized position at the handlebar
Parameter: GPS, acceleration	24 Hz	One measurement in 11 s
Parameters: Environment (air pressure, humidity)	Various environment-related data as humidity, air pressure, or temperature are collected. Because of cost reasons a particulate matter sensor was not integrated	Sniffer bike gathers a lot of environmental data as PM10, PM2.5, PM1.0, temperature, humidity, air pressure, and volatile organic compounds
Real-time data transfer	–	x
Hourly values	x	x
Average speed	11.89 km/h (moderate weather conditions) 12.12 km/h (strong wind, heavy rain, etc.)	13.89 km/h (province of Utrecht) 13.34 km/h (Zwolle)
Average distance	3.59 km (good weather conditions before a trip starts) 3.01 km (bad weather conditions before a trip starts)	7.05 km (province of Utrecht) 7.01 km (Zwolle)
Average duration	18:09 min (good weather conditions before a trip starts) 15:16 min (bad weather conditions before a trip starts)	34:56 min (province of Utrecht) 39:21 min (Zwolle)

The collected and preprocessed bicycle sensor data can be applied (1) for the improvement of the bicycle path and road network; (2) to make cycling safer, cleaner, and more acceptable; (3) to make cycling more comfortable and faster; and (4) research factors for "cycling happiness" and infrastructure quality could be abbreviated. Especially regarding the ECOSense approach the question remains how the results can be interpreted in terms of infrastructure quality and recommendations for potential cycling promotion measures. As part of further investigations which could consider further traffic data (e.g., construction conditions of the infrastructure) concrete quality categories could be deduced that could support the municipality in prioritizing measures. In a next step, the data-driven connection of the bicycle to other means of transport will enable a "real" multimodal traffic management. Nonetheless, further investigations need to be conducted in order to design a sensor system, which could address further requirements (e.g., battery life, faster feedback between municipalities and citizens). Additionally, research should be done about new data-driven approaches which allow the harmonization of different bicycle sensor datasets, in order to make different European cities and regions even more comparable.

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[26] https://www.bmvi.de/DE/Themen/Digitales/mFund/Ueberblick/ueberblick.html.

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Success Factors for Measuring Smart Campus Data Initiatives: A Response to Sustainable Transformation at Higher Education Institutions

Anthea van der Hoogen, Rutendo Chibvupe, Brenda Scholtz, and André P. Calitz

Abstract Sustainable digital transformation is a global process at Higher Education Institutions (HEIs), who need to monitor the factors that measure their smart campus initiatives. The purpose of this chapter is to report on an analysis of factors for Smart Campus data initiatives that contribute to sustainable transformation. The chapter therefore addresses the research question: "*What success factors can be used by Smart Campuses to guide and measure data initiatives for sustainable digital transformation?*" A case study approach was used and the case was one of the comprehensive universities in South Africa. The primary data collection method was through interviews, which were conducted online with key stakeholders of a Smart Campus. Convenience and purposive sampling were adopted, with a deductive research approach. The Qualitative Content Analysis process was followed to analyze the data obtained through interviews on the topic of Smart Campus data initiatives. From the interview data the factors related to the digital activities, their purpose, related data sources, and the value of such activities and data were identified. The contribution is the set of factors that can be used by stakeholders of Smart Campuses for planning or measuring sustainable transformation while addressing digital research and education. This chapter proposes that stakeholders should capitalize on the accelerated digital age caused by the COVID-19 pandemic to assist with sustainable transformation at universities.

Keywords Digital transformation · Research and education · Sustainability · Higher education · Smart campus

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1 Introduction

Digitalization is embedded in the everyday life of most societies, with emerging technologies such as artificial intelligence, virtual reality, the Internet of Things (IoT), and cloud computing producing a disruptive effect on day-to-day activities (Grosseck et al., 2020). Digitalization is defined by i-Scoop (2021) as "*the profound and accelerating transformation of business activities, processes, competencies and models to fully leverage the changes and opportunities of digital technologies and their impact across society in a strategic and prioritised way.*" i-Scoop (2021) also defined digital transformation as "*the cultural, organisational and operational change of an organisation, industry or ecosystem through a smart integration of digital technologies, processes and competencies across all levels and functions in a staged and strategic way.*" Sustainable transformation involves the investigation of roadmaps to the implementation thereof to meet the present-day needs without compromising the ability of future generations meeting their own needs (Robert et al., 2012). Digitalization has, for a long time, been an integral part of service delivery in education. In the last two decades, Higher Education Institutions (HEIs) have adapted their strategies to improve their provisions of innovative digital solutions (Tay & Low, 2017). However, the implementation of these strategies has been accelerated even faster over the last 2 years due to COVID-19 pandemic disruptions (World Economic Forum, 2020). These disruptions have had a major impact on the job market as well as on the education sector, especially the higher education sector (Bhagat & Kim, 2020). The need for sustainable transformation in the digital age within HEIs has also accelerated (Houlden & Veletsianos, 2020). Sustainable transformation refers to flexible, resilient, and inclusive digital resource adoption (Houlden & Veletsianos, 2020; World Economic Forum, 2020). As a response to sustainable transformation and the increase in research and education activities, more disruptive technologies and open data sources are required.

Sustainable transformation through digitalization in HEIs directly implies remote and online learning as a predominant alternative for the facilitation of lectures. This transformation had to be implemented to curb and minimize the spread of the COVID-19 virus (Bhagat & Kim, 2020). Bhagat & Kim (2020) argue that issues relating to access to technology, the quality of online learning, financing and available infrastructure can prove to be strenuous to both students and academics. In addition to these issues, findings from a study conducted by Bond et al. (2018) dictates that digital tools as a learning alternative are not the preferred option for both students and teachers in performing absorptive and practical tasks. In developed countries such as China, which is ranked as one of the fourth most developed countries in the world based on their Human Development Index (UNDP, 2019), structures have been developed to facilitate digital-based learning in Hong Kong as part of a joint initiative between government and HEIs (Liu et al., 2019). Despite China's economical and technological advancement on a global scale, it still faces challenges such as insufficient technical support. In the African context, challenges around digital-based learning are amplified due to the hindered technological growth caused by economic limitations (Chakravorti & Chaturvedi, 2019). Notwithstanding these difficulties, South Africa has displayed some areas of excellence in digital transformation in driving education forward during the pandemic (Mhlanga & Moloi, 2020). HEIs in South Africa are governed by the Department of Higher Education and Training (DHET), whose mission is to develop a fully inclusive post-school system that will produce capable and qualified citizens suited for the 4th Industrial Revolution, and a modern national and international community (DHET, 2021). The DHET is responsible for approving all programs that are run in public HEIs across the country, with the assistance of the Higher Education Quality Committee (HEQC) and the South African Qualifications Authority (SAQA) (Zawada, 2020). In South Africa, HEIs are classified into three different types, namely, Technical Vocational Education and Training (TVET) colleges, universities of technology, and universities (Smit, 2017).

HEIs can serve as sources of data, or data hubs, and this data can be processed for relevant use in Smart Cities through data science and deep learning algorithms (Costa & Peixoto, 2020). Smart Cities are characterized by modern Information Technology (IT) infrastructure fuelling sustainable economic growth and a progressive quality of life for its inhabitants (Alawadhi et al., 2012). To drive digital transformation and create smart solutions using open data and data sources, disruptive technologies such as Big Data, the IoT, and digital platforms are required (Deloitte, 2015), since data is a key technological element in any Smart City solution (Allam & Dhunny, 2019). It is therefore recommended that both technology and data in the digital context are considered as factors for planning, measuring, and assessing the success of Smart City initiatives. Smart City initiatives are the result of a community's need to "*harness physical infrastructures, information communication technologies (ICT), knowledge resources and social infrastructure for economic regeneration, social cohesion, better city administration, and infrastructure management*" (Ojo et al., 2015, p. 43). One such initiative is a Smart Campus, which is an integral part of the Smart City framework as it facilitates smart learning, which, in turn, creates a smart workforce (Dong et al., 2020). Min-Allah & Alrashed (2020) describe a Smart Campus as an initiative that allows educational institutions to combine smart technologies and available infrastructure for improved services, decision making, and campus sustainability. Smart campuses provide supportive and engaging experiences for its users through advanced network infrastructure and IoT devices (Jones, 2021). The goal of a Smart Campus is to adopt IT and digital innovation so as to improve efficiency and promote sustainable transformation at universities (Lu et al., 2019).

In smart campuses, the role of technology and data is of great importance to their stakeholders; particularly in light of the digital educational strategies that urgently needed to be implemented due to the COVID-19 pandemic (Rashid & Yadav, 2020). The pandemic has therefore accelerated the critical need for IT skills, which have become even more vital for future professionals as digital competence has become a basic requirement in the current industrial and economic climate (Bond et al., 2018). Contrary to predictions by a Harvard Business Review report that Africa's digital economy would exponentially increase due to its young age demographic, digital economic growth has, in fact, decreased (Chakravorti & Chaturvedi, 2019). This decrease is of major concern across all educational sectors as historical, institutional, and structural barriers limit the access and skills required to adequately use technology and sufficiently implement the concept of digital inclusion (National Digital Inclusion Alliance, 2021). The National Digital Inclusion Alliance (2021) defines digital inclusion as "*the activities necessary to ensure that all individuals and communities, including the most disadvantaged, have access to and use of Information and Communication Technologies (ICTs*)."

One way of determining the success of Smart City initiatives and, therefore, a Smart Campus, is to determine the value of these initiatives for all stakeholders and whether gaps exist, or not (European Commission, 2014; Flak et al., 2015). Some studies, such as that of Deloitte et al. (2021), van der Hoogen et al. (2020), and Lu et al. (2019), have proposed dimensions and factors of Smart Cities. However, there are limited studies that report on actual empirical evaluations of Smart Campus initiatives with stakeholders related to these factors, especially in South Africa. Therefore, the research problem that this chapter addresses is how to determine the plan and monitor the success of Smart Campus data initiatives, particularly initiatives for sustainable transformation. This chapter addresses this problem and seeks to answer the research question, "*What success factors can be used by Smart Campuses to guide and measure data initiatives for sustainable digital transformation?*" The findings form part of a larger project conducted as part of a PhD study on Smart City initiatives (van der Hoogen, 2021). The methodology used to answer the research question is the framework for an integrated methodology (FraIM) proposed by Plowright (2011) and the case study approach (Sarker et al., 2018; Yin, 2014). The case is one of the comprehensive universities in South Africa. Secondary data was collected and analyzed by means of a literature review, while primary data was collected by means of online interviews with key stakeholders of a university in the Eastern Cape province of South Africa. The sampling techniques were purposive and convenience (Saunders et al., 2009). The Qualitative Content Analysis (QCA) process was followed as recommended by Schreier (2013) and was used to analyze the literature and interview data, and to identify digital activities, their purpose, related data sources, and the value of these activities and data. The contribution of this chapter is to provide stakeholders at HEIs with a set of factors that can be used to plan or measure data initiatives for a Smart Campus that aims at sustainable transformation through digital research and education. The chapter is structured as follows: Sect. 2 reports on the literature review conducted. Section 3 provides the research methodology and design of the research. The results and the evidence of the data collected are analyzed in Sect. 4. Further reflections on the findings from literature and from the interviews took place and some recommendations are made (Sect. 5). The chapter concludes by identifying the contributions of the research and future research areas (Sect. 6).

2 Literature Review

Africa is constantly referred to as the next big growth market, however this has barely materialized, as economic growth in Africa has stalled (Chakravorti & Chaturvedi, 2019). The reasons for this slow economic progress could be pinned to a list of both historic and current attributes, including colonialism, corruption, and politics (Ceesay, 2019). The resultant effects of these attributes commonly include graduate unemployment, under-employment, human capital flight, corruption among policy-makers, and a shortage of workers in the Research and Development sector (Oluwatobi et al., 2018). Africa is a resource-rich continent with great potential that attracts investors. Despite numerous investment efforts in the digital spectrum, the continent struggles to fully benefit from the economic enhancement that comes with digitalization (Solomon & van Klyton, 2020). Solomon & van Klyton (2020: p. 1) argue that this lack of economic prosperity, associated with digitalization, is caused by "*a persistent digital divide, including digital skills shortages, deficits in ICT infrastructure, and high-cost structure*s." Taylor (2021) defines digital divide as "*the gap between demographics and regions that have access to modern Information and Communications Technology and those that don't have access.*"

According to College SA (Smit, 2017), TVET colleges offer vocational and occupational courses, equipping students with the respective academic and practical knowledge. Students in TVET colleges do not necessarily require the national secondary education qualification (Matric certificate). Universities of technology mainly offer students diplomas and certificates in career-orientated occupations, with a focus on practical experience. Research universities and comprehensive universities offer undergraduate and postgraduate qualifications with a focus on academic rather than vocational training and have higher entry-level requirements. Both universities of technology and research and comprehensive universities require students to have a secondary education qualification, with universities requiring higher and more specific high school grades (Smit, 2017). South Africa has been merited for its adoption of Fourth Industrial Revolution (4IR) applications during the lockdown that was imposed by the COVID-19 pandemic across all sectors of education (Mhlanga & Moloi, 2020). Mhlanga and Moloi (2020) report that some examples of excellence include the switch to remote (online) learning, the use of zero-rated educational applications and websites, and the launch of digital schools. The digital divide in HEIs is difficult to avoid as most institutions are comprised of an amalgamation of different demographics and income classes. Chakravorti and Chaturvedi (2019) discuss digital transformation and digital literacy as being of paramount importance in such settings, as a lack thereof hampers service delivery in HEIs.

Digital literacy is an elementary requirement for the successful implementation of a Smart Campus as a Smart City initiative and stakeholders of a Smart Campus must possess fundamental digital competence. Spante et al. (2018: p. 10) describe digital competence as the "*confident and critical use of Information Society Technology for* *work, leisure and communication.*" The European Commission (2014) further states that digital competence is dependent on basic IT skills, which entails "*the use of computers to retrieve, assess, store, produce, present and exchange information, and to communicate and participate in collaborative networks via the Internet.*" Most HEIs ensure that their students possess basic IT skills through competency tests and provide modules that teach these skills. These fundamental modules are part of the entry-level curriculum. Technological solutions and platforms, such as Blackboard and Moodle, are key tools in rendering services to students in HEIs. Moodle, which stands for Modular Object-Oriented Dynamic Learning Environment, is a learning management system that helps educators create quality online learning environments (Suartama et al., 2020). The COVID-19 pandemic has seen the wake of new software being used at local HEIs as learning management systems, such as Blackboard's Ally at the University of Pretoria (IT Web, 2021). Ally can generate alternative formats of course delivery to reach students with different learning and access capabilities. Meeting tools, such as Zoom and Microsoft Teams, have been key to the facilitation of virtual learning environments. Microsoft Teams allows students to attend lectures, engage in discussions, and submit assignments, amongst other features (Martin & Tapp, 2019).

Kirimtat et al. (2020: p. 86448) derive the term Smart City from "*the adoption and application of mobile computing systems through practical data management networks amongst all components and layers of the city itself.*" Therefore, a Smart City is comprised of nine dimensions that are pertinent for the success of a Smart City, Smart Campus, or related initiatives (van der Hoogen et al., 2020). Two of these dimensions, i.e. Smart People; and Smart Technology and ICT Infrastructure are regarded as support dimensions to all other Smart City dimensions (van Der Hoogen, 2021). The Smart People dimension represents the human aspect of a Smart City and consists of individuals, communities and groups, such as government, enterprise, and social organizations (Shen et al., 2018).

The factors for the Smart People dimension identified by Giffinger & Haindlmaier (2010) and confirmed by van der Hoogen (2021) are:

- Level of qualification;
- Affinity to lifelong learning;
- Social and ethnic plurality;
- Flexibility;
- Creativity;
- Cosmopolitanism/Open-mindedness;
- Participation in public life and Smart City initiatives; and
- Synergies through partnerships and collaborations.

Level of qualification refers to a person's proficiency and competence of a particular skill based on knowledge acquired from an educational institution (Nidirect Government Services, 2021). **Affinity to lifelong learning** is the innate need for Smart People to constantly learn new skills, acquire information, and update their knowledge base (Zhuang et al., 2017). **Social and ethnic plurality** is the coexistence of people from different backgrounds and lifestyles in a harmonious system. Pluralism leads to decision-makers negotiating solutions for the common good of the entire society (Longley, 2019). **Flexibility**, in this context, is the people's ability to adjust to ever-changing environments and conditions emotionally and intellectually. Stein & Book (2011) further define flexible people as agile, synergistic, and capable of adapting to change. **Creativity** speaks to the inventiveness and innovation of Smart People. **Cosmopolitanism/Open-mindedness** facilitates people of different cultural backgrounds to meet and learn about and from each other in a productive way (Teachers College Columbia University, 2009). **Participation in public life and Smart City initiatives** involves the Smart City citizens' proactive use of its infrastructure and engagement in Smart City projects (Simonofski et al., 2017). This factor is closely related to **Synergies through partnerships and collaborations** as participation and collaborations amongst Smart People are especially important for a successful and sustainable Smart City. Synergies in partnerships refer to the joint actions of separate parties to produce a combined effect that is greater, more useful, and more sustainable than separate efforts (Turner & Uludag, 2015). All these factors are key to the successful implementation of Smart City initiatives.

The implementation of smart cities in developed countries has faced challenges. A study of China shows that Smart City programs are lacking, as its citizens generally have difficulty accessing IT services (Shen et al., 2018). In Africa, challenges hindering Smart City and IT development are augmented by poor project implementation, improper use of equipment, inadequate training for stakeholders, and a lack of follow-up or maintenance (Wells & Wells, 2007). Although these challenges are still pertinent across the continent, many African economies are realizing that digitization and IT infrastructural development allow for modern sustainable business models and employment creation (Ndung'u, 2018). In recent years, the education sector has seen considerable initiatives to improve the quality of education through the use of IT. More schools and HEIs are being equipped with digital resources for teaching, learning, and administrative tasks (Agyei, 2020).

The **Smart Technology and ICT Infrastructure** dimension considers the following three main factors:

- Smart technologies;
- Smart data; and
- Availability of ICT infrastructure.

Smart technologies are a success factor for HEIs since these technologies have helped define the dawn of a new research area termed Smart Education. Smart Education offers students and teachers new approaches, learning technologies, processes, and strategies to optimize deliverables and allocation of resources (Ţălu, 2020). Smart Education outlines the learning process in the digital age where all aspects are created, coordinated, and intelligently designed. Smart technologies, in the context of Smart Education, promote the formation of educational activities on the Internet, and the distribution of knowledge amongst students (Lyapina et al., 2019). Smart technologies also harness a valuable and complex network of relations between companies, universities, research institutes, and other support structures and endorse high standards across the network of all HEIs (Ţălu, 2020).

Smart data is described as "*digital information that is formatted so it can be acted upon at the collection point before being sent to a downstream analytics platform for further data consolidation and analytics*" (TechTarget Contributor, 2016). This data is independent of software applications and is extracted using intelligent algorithms that translate the data to useful information that is self-describing and self-protecting (Dix, 2018). Smart data can be produced inexpensively through the use of sensors, chips, and actuators (Majeed & Ali, 2018). Majeed and Ali (2018) report that data from humans is assembled and acquired constantly without their acknowledgment. Applications installed onto our devices and wearables, controlled by sensors, allow for information to be gathered with limited correspondence from the user. The gathered information can be used to enhance teaching and learning environments, students' healthcare management, classroom management techniques, campus security, and attendance monitoring (Majeed & Ali, 2018). The ability to collect and manage data, and effectively extract information, is important for a Smart Campus to provide research insight and improvements to services and facilities by creating collaboration and integration amongst the different components (Curry, 2016).

Availability of infrastructure refers to the physical and virtual availability of frameworks that allow for the adequate operation of a Smart Campus. In developing countries, ICT or IT integration in learning institutions is still facing challenges due to the lack of investment in IT infrastructure and the professional development of staff (Rana & Rana, 2020). Based on a study conducted in Nepal, Rana and Rana (2020) report that limited IT resources, such as weak Internet connectivity and current devices, irregular power supply, and negligible administrative support, hamper the user's access to a wide range of digital information. This lack of access, in turn, accelerates teachers' unwillingness to adopt IT as a learning aid. The use of IT related gadgets is prevailing across all demographics, and many benefits can be leveraged from this, but the shortages in infrastructure at educational institutions are still a major concern. Narrowing the scope of developing countries even further emphasizes the digital divide between urban and rural communities, where there is a substantial variation regarding the quality of IT infrastructure (Woyo et al., 2020).

3 Research Objectives and Methodology

The following two research objectives were extended from the initial PhD study to answer the research question of this chapter:

RO1: To identify the success factors of data initiatives for HEIs; and

RO2: To provide recommendations to HEIs to guide and measure sustainable digital transformation.

The framework for an integrated methodology (FraIM) proposed by Plowright (2011) was adopted to guide this research and to meet these objectives. FraIM has a

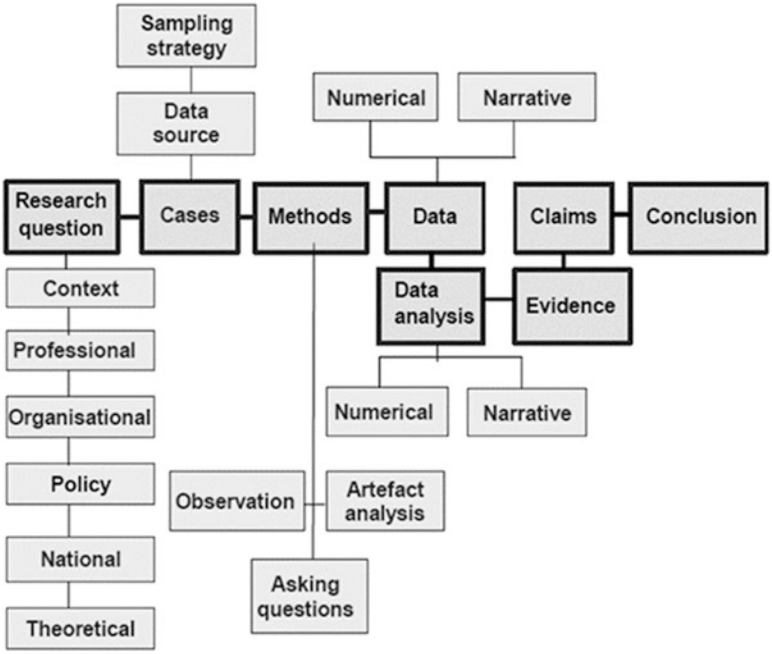

Fig. 1 The extended structure of FraIM (Plowright, 2011)

basic linear structure and an extended structure of eight components with elements for each component that can represent any research project activity (Fig. 1). The next few sections outline how FraIM was adopted in this chapter.

3.1 *Contextualization of the Research Question*

The first component is the **research question** of this study which is identified as: "*What success factors can be used by Smart Campuses to guide and measure data initiatives for sustainable digital transformation?*" The question is grounded in the five different contexts of FraIM contexts. The **professional context** includes those stakeholders who are described as the professionals from different disciplines and are key to contributing to Smart Campus data initiatives. The **organizational context** considers the organizations, backgrounds, and professions of the researchers. In this research, the organization is viewed as the Smart Campus that enables planning and analysis from the impact of technological benefits (Batty et al., 2012). The professions of the authors are all in the fields of Information Systems and Business Management, while all authors are citizens of the Eastern Cape Province of South Africa and are employed by the Nelson Mandela University.

The **political context** of the study is the political environment of South Africa, as this is the country where the case of the Eastern Cape Province is situated. Liveable, sustainable, and inclusive governance are some of the trending issues that have been identified by Allam (2018). In South Africa, especially in the Nelson Mandela Bay Municipality, corruption in government is rife and has been referred to as an endemic (NMBM, 2016). Other challenges in South Africa are poverty, unemployment, the digital divide, and personal safety and security; these challenges are also evident in other cities in developing countries for example, South and East Mediterranean cities (Monzon, 2015). The importance of data for service provision in Smart Cities has been clearly highlighted (Albino et al., 2015; Kassen, 2017; Scriney et al., 2017; Yadav et al., 2017). Open data were identified as an important success factor for providing access to data in Smart Cities (Lea & Blackstock, 2014; Yadav et al., 2017). However, in South Africa, the right to data access and open data needs to be weighed against an individual's right to privacy of information. These rights are guided by the Protection of Personal Information Act (POPIA) for the people in South Africa (POPIA, 2020).

The **national context** of this study is in the Eastern Cape province of South Africa, which, from the viewpoint of South African higher education, is governed by the DHET. The **international context** to be considered is the United Nations Sustainable Development Goals (SDGs) and, particularly SDG11, which is to "*Make cities and human settlements inclusive, safe, resilient and sustainable*" (United Nations, 2015, p. 21). For the **theoretical context**, the Technology, Organization, and Environment (TOE) theory (DePietro et al., 1990) was considered as a suitable theory to undergird the research, due to the focus on these three contexts in Smart City research. This theory is used to determine technology usefulness and the value of technology innovations for all users and stakeholders (Baker, 2012). Another study used the TOE theory to measure the readiness of a Smart City and reported that data analytics and data management are technology enablers (Dewi et al., 2018).

3.2 The Case Study, Sampling, and Data Collection

Cases is the second component in the FraIM methodology and is described as any source of data collection. In this study, the case is one of the comprehensive HEIs in the Eastern Cape Province. The case study strategy was selected based on reasons highlighted by Yin (2014), to contribute to the knowledge of the related phenomena; in this case, the citizen, investors, and other stakeholders. A case study is about the scope. It is an empirical inquiry of a real-world context where in-depth investigations take place. The phenomenon and the context of a case study are needed where there is difficulty representing the case's real-world context. Robson (2002) provides the argument that instead of statistical generalization, case studies can provide analytical findings, and thus theory can be developed to contribute to the understanding of other similar cases and scenarios. Yin (2014: p. 17) also describes the methodological characteristics of a case study inquiry, and one of these are of particular relevance in this chapter, described as follows: *"copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result."* The sampling techniques used were purposive and convenience sampling. Purposive sampling was selected as a specific purpose was required for participants to be selected (Saunders et al., 2009). The data collection requirements included participant knowledge of Smart City initiatives and their understanding of the information required for their Smart City campus initiatives, as well as the digital activities of their initiatives. The participants were selected based on the authors' networks of contacts, and therefore convenience sampling was a suitable technique.

3.3 Warrantable Research

Plowright (2011) emphasizes that warrantable research (also referred to as valid or authentic research) is achieved once the FraIM methodology is followed and outlined in detail by the researcher for each component. Ensuring validity through triangulation was also conducted using the following methods (Guion et al., 2011);

- **Data triangulation:** the use of multiple data/information sources from different groups. Different stakeholder groups/types, i.e. providers and users or types (Table 1), allowed for triangulation from each stakeholder group for the evaluation;
- **Investigator triangulation:** where multiple investigators or evaluators form part of an evaluation team. In this study the coding frame was checked by different coders;
- **Theory triangulation:** the use of multiple professional perspectives is referred to for interpreting a single data or information set (Sects. 2–4); and
- **Methodological triangulation:** where more than one data collection and analysis method is used. In this case, both narrative and numerical methods were used.

In addition to triangulation, the following strategies were used to ensure the reliability and validity of this research:

- **Coding consistency (independent parallel coding)** (Thomas, 2006): the different sets of categories/themes were compared to eliminate any overlapping, after which the sets could be merged. Three coders (the researcher and two other

Table 1 Profile of interview participants

P#	Participant job description	Perspective of initiative
P7	Program Manager—Innovation through engineering	Smart mobility
P11	Sustainability Manager—Infrastructure Service & Space Operations	Infrastructure service and space operations
P14	HoD—University	Learning and teaching

coders) checked the raw data using a coding framework as part of the QCA process (Sect. 3.4), and a fourth coder eliminated overlapping themes. The second and third coder also confirmed which sample quotes to include from the interviews;

- **Chain of evidence:** to ensure reliability throughout the study (Yin, 2014). The chain of evidence was followed methodically. Information was shared with the participants beforehand to check the objectives of the study and interview structure. Additionally, peer reviewer feedback was considered throughout the main PhD study, and
- **Ethical consideration**: the ethics application approval process was followed in line with that of the university of the PhD study, the Nelson Mandela University and ethics clearance was obtained with reference no. REF-H18-SCI-CSS-004.

3.4 Data Analysis

The fourth component is related to the types of data collected, namely **transcription documents/artifacts** that included **narrative data**, which were loaded into Atlas.ti. In the fifth component, the data were analyzed **numerically and narratively** to establish different types of codes, themes, and sub-themes. For this component, the eight steps of the QCA process, as recommended by Schreier (2013), were followed. A summary of these steps is provided in Table 4 in Appendix. Step 3 of the QCA process allowed for building the coding frame for the data set. Excel and Atlas.ti were used for manual data handling, identification and visualization of codes and themes. The research instrument was the interview guide (Table 2), which had questions that were based on the main research question and literature. Saturation is an important concept in collecting and analyzing qualitative/narrative data and is described by Schreier (2013) as the point at which no additional or new themes can be found or identified. The QCA process followed included steps of saturation, where the coding frame of the different themes was created (Table 5). Saturation became evident when the themes from Round 1 interviews, and those themes from literature, were similarly identified for the same questions addressed in Round 2 interviews as in Round 1. Saturation of the themes also became evident when similar comments came through in the later interviews to those made in earlier interviews of Round 2. The last three components of FraIM are reported on in the following three sections. The **evidence** is the sixth component and is discussed in the results section (Sect. 4). The **claims** is the seventh component and is presented in Sect. 5. The final component, the **conclusions**, is presented in Sect. 6.

Table 2 Interview question guide

Interview questions	References
Dimension: Smart technology and ICT infrastructure (including built infrastructure):	
D2. Data (digital) value chain:	Curry (2016)
D2.1 Which digital activities do you use for your Smart City initiatives?	
D2.2 What phases of the data value chain are relevant to your initiative?	
D2.3 Which data/open data sources are you using?	Kassen (2017)
D2.4 For which purpose was the above-mentioned data/open data sources used?	Yadav et al. (2017)
D2.5 What is the value of using the above-mentioned data/open data sources? (i.e., do you have any problems with getting the data or with the quality of the data)? *D2.6 (omitted from this second round of interviews as it was only applicable to the stakeholders from round 1)*	Curry (2016)
D2.7 What are the challenges of using the above-mentioned data/open data sources?	Kassen (2017)

4 Results

Only three of the 16 interviews are reported on in this chapter, which are those related to Smart Campus initiatives. Section 4.1 describes the participant profile, the interview question guide, and the coding frame. The sections following thereafter highlight the findings from the interview data for each of the interview questions summarized in Table 2. The themes and sub-themes are shown for the data and open data source challenges in Sect. 4.2; for the value chain digital activities in Sect. 4.3; data and open data sources in Sect. 4.4; the purpose of using these sources in Sect. 4.5; and the value of using such data and open data sources in Sect. 4.6.

4.1 Participant Profile, Interview Question Guide, and Coding Frame of Themes

Three participants represented projects related to initiatives at the university (Table 1). One participant (P7) was from a Smart Mobility perspective on campus, another (P11) was from the Infrastructure Service and Space Operations department, and the third participant (P14) was Head of Department (HoD) of an academic department at the university and represented the Learning and Teaching perspective. The interview questions guide (Table 2) included six questions from the Technology context of the TOE theory. Each of the questions was confirmed in literature. The findings are classified according to the primary Technology and Data constructs of TOE and then according to the prevalent themes and sub-themes identified in the QCA. The interview transcripts were divided into units (i.e., interview questions) to represent the units of raw data (Step 4 in Table 4). The data evidence from the

Table 3 Success factors for a smart campus to measure sustainable transformation (authors construct)

<table>
<tr><th>Smart technology and ICT infrastructure</th><th>Smart people</th></tr>
<tr><td>Smart technologies
• Smart data
Availability of infrastructure (including built & ICT)</td><td>Level of qualification
Affinity to lifelong learning
Social and ethnic plurality
Flexibility
Creativity
Cosmopolitanism/open-mindedness
Participation in public life and Smart City initiatives
Synergies through partnerships and collaborations</td></tr>
<tr><td>Connectivity
• Data, IT and cyber security
• Service provider lock-in
Access to resources
• Costs (process, budget and subscriptions)</td><td>Challenges of using data/open data sources
• Skills/understanding to make sense of big data</td></tr>
<tr><td>Purpose and value of data and open data sources
• Connectivity (access to real-time; secure and online resources; and remote access to data)
• Visualization models
• Integration of power-grids
• Data gathering
• Data integrity</td><td>Purpose of using data and open data sources
• Reporting and monitoring
• Sustainability (resource management and awareness)
• Affordability
• Decision making for better solutions</td></tr>
<tr><td colspan="2">Data value chain</td></tr>
<tr><td colspan="2">Data acquisition
• Trackers/sensors/meters
• Digital portals/databases
• Sustainability (resource and energy management systems)
• Sustainability (mobile and web applications for utilities and waste management)
Data usage
• Data streaming (dashboards, decision making)
• Online shopping/services/streaming
• Usage patterns
• Online learning
• Maintenance (schedule for electric vehicles)
Data analysis
• Algorithms to predict the source of energy
• Online research
Data storage
• Cloud computing and batteries (for electric vehicles)
Data curation
Online research data quality</td></tr>
</table>

interview transcriptions and the sample quotes are provided verbatim to maintain the authenticity of what the participants said during the interviews. Table 5 in Appendix provides a summary of the coding frame of all the themes and sub-themes identified per interview question.

4.2 Data and Open Data Sources Challenges

The two themes and related sub-themes for challenges related to the Technology context (which includes data and open data sources) are:

- *Connectivity*-Data ($f = 3$)
  - Data, IT and Cyber Security (P7);
  - Service Provider Lock-In (P11); and
  - Making Sense of Big Data (P14).
- *Access to Resources*-Data ($f = 2$)
  - *Costs* (Process and Money) (P14); and
  - Subscriptions (P14).

Regarding the data and open data sources challenges, P7 said: *"...From our perspective, it hasn't happened yet; is safety and security issues, because now these are open data sources. There might be a safety and security issue or exposure to data breaches. That's the only one we haven't experienced yet."*

P11 stated that "*...in the long term, let's say lock in that you find with certain software's packages or whatever. So, in many cases we find that is quite a challenge. The moment that somebody moves out of the Metro, which previously serviced us on a certain package, or whatever, then it becomes a massive issue for us to keep ongoing. So, you almost want to. Really be comfortable that what you apply would be able to last you along time in relation to service ability. The integration with other systems, the ease of integration...So if you want to break free from a certain service provider and you want to change something, you know what happens with all those historic data that's placed on a cloud somewhere. You know would you be able to still access that....*"

P14 said: "*Paid for sources is the cost. Also, with your data, so that you have such an abundance of data that you have access to, so be able to make sense of it and narrow it down...So making sense of the data I think is a big challenge...if it's behind a paywall in the cost of accessing that data....*"

4.3 Data Value Chain Digital Activities

The data value chain activities proposed by Curry et al. (2012) include the requirements in collecting smart and digital data in Smart Cities and, in particular, Smart Campuses. An example provided by Curry (2016) relates to the data analysis activity where volumes of Big Data were collected using the concept of Smart City data (data from sensors, social media, citizen mobile reports, and municipality tax data). The five main phases of these activities are Data Acquisition, Data Usage, Data Analysis, Data Storage, and Data Curation. It was therefore deemed appropriate to use these phases as questions for the interviews, which became the themes for the QCA. In our context, they are related to Smart Campus initiatives. A network diagram created with Atlas.ti was used to design and show the QCA themes of the data value chain phases and the related sub-themes (Fig. 2).

For **Data Acquisition** the following six sub-themes were identified ($f = 7$):

- Trackers/Sensors/Meters (P7, P11);
- Digital Portals/Databases (P14);
- Sustainability (Resource and Energy Management System) (P7);
- Sustainability (Mobile and Web Applications—Utilities and Waste Management) (P11);
- Usage Patterns (P7); and
- Excel Spreadsheets (P11).

For **Data Usage** the following four sub-themes were identified ($f = 5$):

- Data Streaming (Dashboards, Decision Making) (P7, P11);
- Online Shopping/Services/Streaming (P14);
- Online Teaching and Learning (P14); and
- Maintenance (Schedule for Electric Vehicles) (P7).

For **Data Analysis** the following sub-themes were identified ($f = 2$):

- Algorithms for Energy Source Prediction (P7); and
- Online Research (P14).

For **Data Storage** the following two sub-themes were identified ($f = 2$):

- Cloud Computing (P14); and
- Batteries for Electric Vehicles (P7).

For **Data Curation** only one sub-theme was identified ($f = 1$):

- Online Research (P14).

Regarding the digital activities and the relevant data value chain phases, the following was mentioned (P7):

> *…the main activities relate to the gathering of data. So, for example, with our micro-grid facility on (…) Campus…we gather data…to help with the energy management system... the data that we use uses an algorithm to help us predict what source of energy we use at a specific point in time for the E-bikes. We've got a tracker on all the E-bikes so that tracker helps us understand usage patterns, it also helps us schedule maintenance for the electric vehicles….*

P11 highlighted some of the digital utility activities such as electricity, water, waste, and transport, as follows:

> *Electricity is quite well managed, and I often think it's because it's also got a big financial component of our monthly expenses linked to it. And on our utility bill, probably I would say close to 70 or 80 per cent purely on electricity, so it has become something that they really want to look after. So, water, waste and transport, is definitely a much lower database to work from? You know they were very bare in those spaces. It's very much still almost Excel sheets being sent around where if we talk seamless data collection water is getting there*

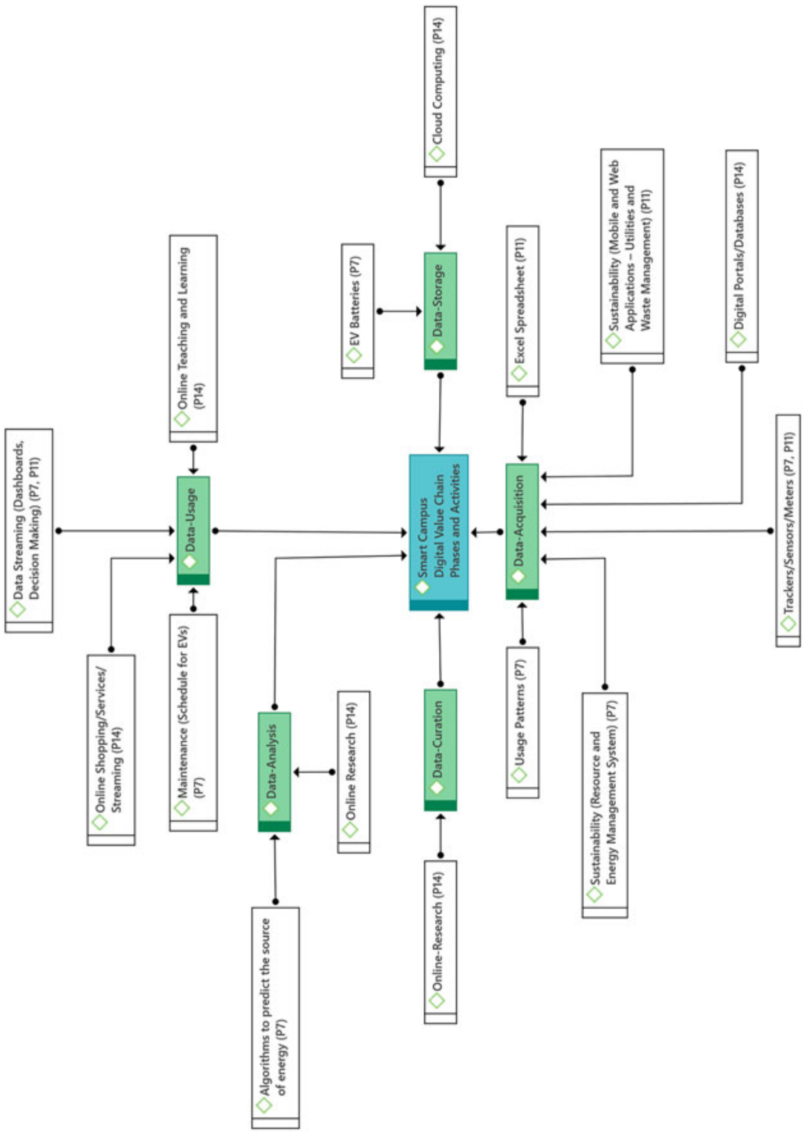

Fig. 2 Smart campus digital value chain phases and activities

slowly.... There's a lot of data being collected from all sides from the municipality where they've got proper metering in place to give you almost ...so you can actually if you needed to make big decisions. Now you can go and look at the last three or four years at the click of a button....

P14 stated that:

I can just think of our file management system now everything is in the cloud...there's nothing really kept on files anymore. Our examinations now were 100% online. I spoke about payment systems where you don't need to have cash anymore. I mean, you can use the various electronic methods or smart card enabled payment systems.

4.4 Data (Including Open Data) Sources in Initiatives

A network diagram from Atlas.ti was designed and drawn to show the data sources and types of data sources (Fig. 3). This illustration is based on the findings from the interviews and is therefore not a complete outlook for any Smart Campus, but rather an overview of a particular Smart Campus case study.

Different data and open data sources were identified for the initiatives at the Smart Campus, with the following three themes:

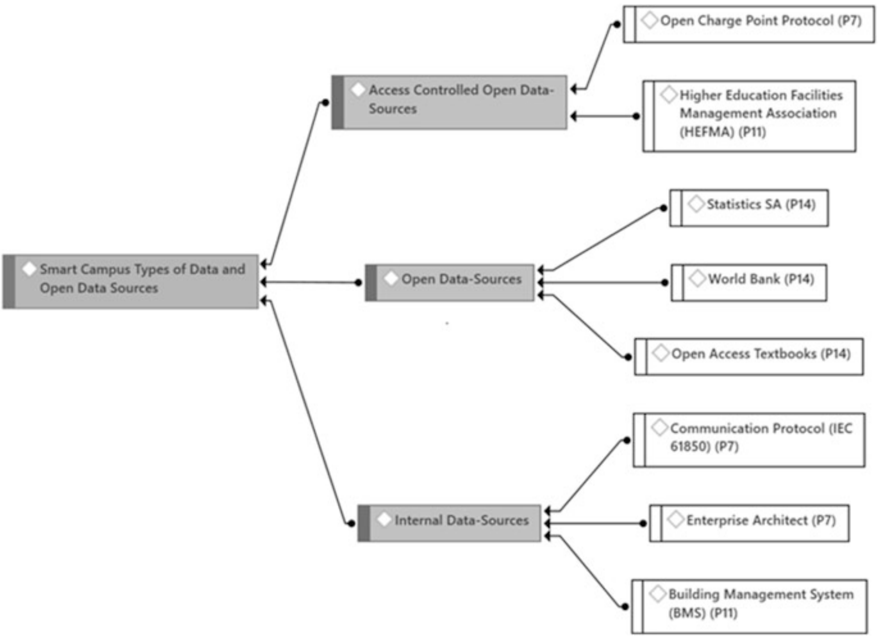

Fig. 3 Smart campus data types and open data sources

- Access Controlled Open Data Sources;
- Open Data Sources; and.
- Internal Data Sources.

For **Access Controlled to Open Data Sources** the following sub-themes were identified (*f* = *2*):

- Open Charge Point Protocol (P7); and
- Higher Education Facilities Management Association (HEFMA) (P11).

For **Open Data Sources** the following sub-themes were identified (*f* = *3*):

- Statistics SA (P14);
- World Bank (P14); and
- Open Access Textbooks (P14).

For **Internal Data Sources** the following sub-themes were identified (*f* = *3*):

- Communication Protocol (IEC 61850) (P7);
- Enterprise Architect (P7); and
- Building Management System (BMS) (P11).

Regarding the **Internal Data Sources** that are being used, P7 said *"...for our Chargers we using a protocol called Open Charge Point Protocol which helps us access data easily from the charger and then for our micro-grid to help us connect easily to the municipal utility grid. We use a* ***communication protocol*** *called IEC 61850 so those online tools that we use really assist us for gathering and processing data, and then we use another one called Enterprise Architect which helps us visualise data and try and develop business cases...."*

P11 also mentioned their Building Management System (BMS) as a main data source and said: *"...until maintenance programs everything at the moment is paid for. Software...there is links to HEFMA which is the Higher Education Facilities Management Association. It's mainly through the* ***Building Management System*** *we're using, so it's (...) controls, linking all our systems that we have onto (...) and then there's the Maintenance Connection is our maintenance program that the University uses...And then very recently, ...because it's financially I don't think a big burden to University is that we would be starting to use Archi bus, which is also a software program...But it's definitely a potential game changer for us in that area of linking many systems into one platform and being able to report and work with data properly...space usage, your financial systems, occupation of areas and water usage and energy. Transport, yeah, your entire HR system linked to space allocation...."*

Several other data sources identified by P11 were described as potential sources to be used if the correct queries are available to collect and analyze the data for the needs of HEI management. Some of the open data sources, specifically related to HEIs, have been said to have little usable data for comparisons between HEIs. His organization is looking at newer systems with better data integration for reporting purposes on environmental and transport data.

With regard to the Open Data Sources that are being used, P14 indicated the use of **Open Access Textbooks** for access by the university and said: "*But other sources of data just depend on the tasks. If it's from the research side you're looking at databases…Statistics SA Databases, World Bank... You know that those open always it paid for. Some of it is open, some of it is open for everyone, some of which you have to drill down a bit and have access, get permission to get access to it. If I think of our textbook situation, OK, there we have open source, and you have your traditional, so, your open source would be Open Access, open source textbooks and knowledge that anyone can access those downloaded for free as your traditional sources which are behind a paywall.…"*

4.5 Purpose of Using Data/Open Data Sources

Five themes were identified for the purpose of using data sources, with no sub-themes:

- Access to Resources for Research (Online Information) (P14);
- Reporting and Monitoring (P11);
- Develop a Visualization Model (P7);
- Remote Access to Data (P7); and
- Integration of Power-Grids (P7).

With regard to the purpose of the data and open data sources, P7 indicated three reasons for using these sources as highlighted here and said *"Enterprise architect was used to develop a visualisation model for our micro grids and with that we were able to develop a business case for utilising a grid which has access to different types of renewable energy sources… the Open Charge Point protocol that was used to help us have* ***remote access to our data*** *from the charging stations. And the IEC61850 protocol we used to assist us with integrating our micro-grid into the municipal electrical grid."*

P11 also identified managing and monitoring as their core purpose of using data sources, and said: "*…it is being able to report on what we do, so ongoing managing and monitoring it, and then once a year being be able to report that the initiatives that we are undertaking are actually bearing fruit either environmentally, socially or financially, so that would be our greatest goal to continuously be able to monitor what we are busy with on a day to day basis. But once a year or once a quarter, whatever requirements are in the long run that you would be able to report on that and indicate that. The money that we've spent have actually been able to gain us two or three percent a year on using less water or less energy or waste management. We've increased our recyclables by so much. Those type of elements are critical for me."*

According to P14, their department also has a major research focus, and said: "*…we would mainly be in the research side of the work we will be accessing your databases and data sources…and that's the core purpose. The research side of* *things, or just acquiring information for the acquiring and analysing of information....”*

4.6 Value of Using Data and Open Data Sources

Each participant associated the value of using data and open data sources with their respective initiatives at the Smart Campus. The values gained were identified according to the following five themes and sub-themes listed below.

- Connectivity ($f = 3$):
  - **Access** to Resources (Online Information) (P14);
  - Internet Research (Monitoring, Managing, and Analyzing Data) (P14);
  - Decision Making for better Solution Development (P14);
- Data Gathering (P11);
- Sustainability (Resource Management, Awareness) (P11);
- Affordability (P7); and
- Data Integrity (P11).

It is clear that an important factor for the participants was controlled access to open data sources, particularly with regard to online information. The participants specified some examples related to the sensitivity of data such as exam papers and financial information (e.g., about utility accounts). Another important issue highlighted was the importance of access to data from partners who provide external services to the HEI. With regard to the value of data/open data sources, P14 said “*...The value of using these data sources...the one...benefit of having access to all of these data sources that you have information that is up to date and relevant, and then that enables you as well to be able to make correct analysis and...come up with appropriate solutions and conclusions and recommendations to whatever problems you’re trying to solve...it enables us to make better decisions and formulate better solutions to the real world issues....*”

Although the factor of **Connectivity** is important, it was also highlighted as a challenge faced by all participants (Sect. 4.2). The digital **Data Value Chain** phases (Sect. 4.3), especially **Data Usage** and **Data Acquisition**, were found to be key success factors at a Smart Campus for all digital activities that take.

For P7, the quality of data and affordability was important, and said: “*We quite happy with the quality of the data we receive, and I think the value is that those tools are affordable. I think that is the main thing, is affordability. The Open Charge Point protocol is completely free, and then there is a small fee for visual enterprise architecture and the IEC one....”*

P11 emphasized the importance of the stewardship of sustainability and managing the integrity of data and processes, and indicated: “*I think it’s just to create integrity behind what we do...know clear and very recognized systems in place which is actually where the data is generated from and then overtime like I said the* *strong thing for me, especially as the stewardship side to ensure that whatever we continuously do that we are able to do that and use the resources that we have optimally. . .Components of gathering that we are very much, I think at a maturity level where we still just gathering a lot of data slowly moving now into a space where we've got enough to analyse. . .myself appointed, which my focus is this. . .It's just not floating around in our area and in our University, and nobody takes responsibility for it. . . . ."*

5 Discussion and Recommendations

The literature review allowed for the identification of factors related to the Smart People; and Smart Technology and ICT Infrastructure dimensions of a Smart City. The themes identified are all important considerations for HEIs' planning and measuring Smart Campus initiatives and can therefore be considered as potential factors to measure sustainable transformation. They were thus added to the factors from literature to provide a more comprehensive list of considerations for those planning a Smart Campus initiative. The updated list is provided in Table 3, where the ones in italics are the original factors from literature.

The themes that were identified in the interviews regarding the challenges of data sources at a university included the aspects of connectivity related to access to resources, as well as the costs related to access to data sources. Bhagat and Kim (2020) argue similar challenges in the education sector, where they show factors causing strain on both the student and the teacher. These factors are access to technology, quality of online learning, financing, and available infrastructure. Solomon and van Klyton (2020) also highlighted factors such as cause of digital divide due to a lack of IT infrastructure and high-cost structures. Therefore, if a Smart Campus wants to overcome such challenges, it needs to consider the factors of Smart People of Participation in public life and Smart City initiatives; and Synergies through partnerships and collaborations. Liu et al. (2019) agree and indicate that digital-based learning should be a joint initiative between government and HEIs. Liu et al. (2019) also mentioned technical support as a factor; this was confirmed by a participant who stated that technical support can be a problem when service providers change and that there are provider lock-in challenges.

The interview findings identified activities in each of the five Data Value Chain phases proposed by Curry et al. (2012). These phases had related sub-factors from the interview findings for digital activities including to track, to manage, to teach and learn, and to predict. It has been reported that universities are regarded as a source of data and classified as an open data hub (Costa & Peixoto, 2020). This was confirmed under the factors of the different data sources and the types of data sources evident from the interviews (see Sect. 2), where data is regarded as a key technological element of Smart City solutions (Allam & Dhunny, 2019). The COVID-19 pandemic has created a need for open data sources at HEIs to cater for all students and staff, even those with learning and access disabilities. These factors, as a purpose of using such open data sources, are incorporated into the software Blackboard's Ally at the University of Pretoria (IT Web, 2021). The interview participants stated that access to resources, especially remote access, has become part of such solutions at the university. These factors confirm and extend those from literature of Smart technologies, Smart data and Availability of infrastructure (including Built & ICT). To support this access, Level of qualification was mentioned by participants as important at an HEI to implement and steward these factors.

Some of the value of Smart Cities is directly linked to ICT infrastructure for a sustainable economy and for the improvement of the quality of life for citizens (Alawadhi et al., 2012). Related factors identified in the interview data were those regarding sustainability for resource management and awareness, and affordability. All these factors can impact the quality of life of citizens and a city's economy, which was confirmed by participants through the factor *Participation in Public Life and Smart City initiatives*. Deloitte (2015) argued that digital transformation can be achieved when smart solutions are created by using disruptive technologies such as Big Data/digital platforms, and by using open data and data sources. This idea was confirmed by the interview data for factors on Internet research and decision making for better solution development. Curry (2016) proposed that creating improved services in a Smart City is linked to the ability to collect and manage data effectively by extracting information.

The participants confirmed the importance of this ability, especially for a Smart Campus, to provide research expertise and insight. Another factor that emerged was creating collaboration and integration amongst the different components, for example, in a Smart Campus.

Sustainable transformation includes three broad categories which are the foundation of the recommendations in this chapter: flexible, resilient, and inclusive digital resources (Houlden & Veletsianos, 2020; World Economic Forum, 2020). The five recommendations are proposed as follows:

1. Both technology and data in the digital context should be considered as factors for planning, measuring, and assessing the success of Smart Campus initiatives.
2. Use all the related factors per data unit and align these per Smart Campus department, and enforce inclusiveness for all partners' and stakeholders' initiatives.
3. Smart Technology and ICT Infrastructure factors should be enforced at a Smart Campus to achieve digitalization and inclusive digital resources.
4. To achieve flexibility, Affinity to lifelong learning, Social and ethnic plurality, Flexibility, Cosmopolitanism/Open-mindedness, and Participation in public life and Smart City initiatives should be enforced at a Smart Campus.
5. To become resilient, a Smart Campus must focus on outlining the value and benefits for everyone. Therefore, all the factors identified from the interviews for the value/benefits of using data and open data sources should be considered, as well as Smart technologies, Smart data, Availability of infrastructure (including Built & ICT), Level of qualification and Synergies through partnerships and collaborations.

6 Conclusions and Future Research

The interview results highlighted the importance of sources of data (including open data), which were primarily open access textbooks, reporting and monitoring, and remote access to data. Some of the key digital activities reported at the university used in the case study were cloud computing, data streaming, online services, online teaching and learning, digital portals, and smart sensors in meter readings. The value of the data was also identified; these were affordability, access to online resources, support for Internet-based research, and decision making for improved research and development solutions. Within the African context, many benefits have been achieved, especially bridging the digital divide, and ensuring that all levels of education are introduced to the digital era. However, in some cases the digital divide has become wider due to the infrastructure limitations, especially in rural areas and the more disadvantaged communities. The chapter provides managerial recommendations and factors that can be particularly useful to managers, academics, researchers, and other stakeholders of HEIs regarding sustainable transformation. Managers of Smart Campus initiatives can use these factors to guide them in planning such initiatives. Researchers can use them for conducting similar studies in different HEIs or in related educational contexts. The findings highlight how a pandemic can support transformation, in a faster and shorter time-period. However, these accelerated achievements can hinder the measurement of the impact, effect, and outcomes of such endeavors. It is therefore advised, especially in situations such as the COVID-19 pandemic, to be ready to conduct case studies to assist the research and development communities with rich data evidence.

COVID-19 has expedited digital transformation in all aspects of human interaction, including education. This chapter proposed that stakeholders should embrace this digital acceleration in the successful implementation of sustainable transformation in HEIs. The two research objectives in this study were successfully achieved. Firstly, the digital data initiative factors for HEIs were identified, not only from literature, but also from an empirical stance. Secondly, recommendations were made based on the factors to HEIs to measure sustainable digital transformation. These recommendations can be converted into guided steps with associated factors per step, and customized per Smart Campus needs, strategies, and initiatives. The limitation of this study is that the evidence and data collection were from only one university, and only a small subset of three interviews are reported on. Therefore, future research should investigate these factors using a larger sample size and at different universities. Future research is also recommended to implement these factors at different Smart Campuses and to measure the impact thereof on sustainable transformation in terms of the digital data initiatives.

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Appendix

Table 4 QCA steps followed

Steps in QCA process Schreier (2013)	Application in this chapter
Step 1: Deciding on a research question	FraIM contextualization of the research question (Fig. 1)
Step 2: Selecting material	Use of transcribed data from the interviews
Step 3: Building a coding frame	Steps followed: (1) selecting material (i.e., transcriptions); (2) structuring and generating categories or themes; (3) defining themes (main and sub-themes); and (4) revising and expanding the frame (until saturation is reached—no additional new concepts found)
Step 4: Segmentation	The transcriptions were divided into units (i.e., interview questions) so that each unit fitted into exactly one (sub) theme of the coding frame. Dividing the transcriptions into themes requires formal (words, sentences, or paragraphs in the text) and thematic (changes in topic) criteria
Step 5: Trial coding	For example: a unit was entered into a row, a main category/ theme was the column and the cell data was the formal and thematic criteria (sentences, quotes from the transcriptions)
Step 6: Evaluating and modifying the coding frame	The evaluation of codes involved the examination (by coders that were not the researcher) of the trial code sheet results to ensure validity and reliability. This included the units of coding being assigned to both rounds of coding. Higher consistency between the rounds of coding results in higher quality of the coding frame
Step 7: Main analysis	All transcriptions were coded. The results of the coding were organized so that it could answer the research question
Step 8: Presenting and interpreting the findings	Section 4 presents the coding frame as the main result with references to the text matrices in the form of sample quotes. The sample quotes for this chapter were selected by the second and third coder (coders that were not the researcher). The data is also presented in a numeric way by reporting coding frequencies

Table 5 Coding frame for the technology and data context of TOE

Interview question	Themes	Sub-themes
Challenges of using the data/ open data sources?	• Connectivity • Access to resources.	• Data, IT, and cyber security • Service provider lock-in • Making sense of big data • Costs (process and money) • Subscriptions
Phases of the data value chain and digital activities of the Smart City initiatives?	• Data acquisition • Data usage • Data analysis • Data storage • Data curation	• Trackers/sensors/meters • Digital portals/databases • Sustainability (resource and energy management system) e.g., EV batteries • Sustainability (Mobile and Web applications—Utilities and waste management) • Usage patterns • Excel spreadsheet • Data streaming (dashboards, decision making) • Online shopping/services/streaming • Online teaching and learning • Maintenance (schedule for electric vehicles) • Algorithms for energy source prediction • Online research • Cloud computing
Data/open data sources?	• Access to controlled open data sources • Internal/external data sources	• Data sources: Statistics SA; World Bank; BMS; (HEFMA) • Open access textbooks • Protocols: Open Charge Point Protocol; Communication Protocol (IEC 61850) • Enterprise architect
Purpose and value of using data/open data sources?	• Connectivity: Access to data and resources for research (online information) • Reporting, monitoring, and visualization models • Data gathering and integrity • Sustainability (resource management, awareness) • Affordability • Integration of power-grids	• Decision making for solution development

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Introducing a New Car-Sharing Concept to Build Driving Communities for Work-Commuting

Jan-Hendrik Witte

Abstract South Africa is currently facing various mobility problems. On the one hand, more and more people are moving up into the middle class, which increases the number of private vehicles on the roads and leads to congestion, increased pollutant emissions, and overcrowded cities. On the other hand, public transportation in the form of buses and trains are hardly used due to their current state in terms of safety, efficiency, or availability, making low-cost trips much more difficult for people without private vehicles. The daily commute to work becomes particularly challenging due to crowded roads and the lack of public transportation alternatives. During the 2018 HEdIS Summer School, an international group of students from South & West Africa and Germany collaborated to develop innovative ideas to address these issues. Using the design thinking process, a new car-sharing concept was developed to enable the potential formation of consistent driving communities. The goal is to match users who live in close proximity to each other and are employed by the same company or by companies that are near each other. Safety is ensured by only giving access to users who are currently employed by a company with which the platform currently has a partnership. By effectively matching people with the same work commute, it is intended to provide an alternative commuting option that is safer, more efficient, and less time-consuming compared to other available modes of transportation and to overall reduce the number of vehicles on the road to address traffic congestion.

Keywords Mobility · Car-sharing · Design thinking

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1 Introduction

The goal of the HEdIS Summer School 2018 was to find new, innovative, and sustainable ideas to face problems and challenges related to the three core problem spaces currently present in South Africa: Water (Taing et al., 2019), energy (Baker & Phillips, 2018), and mobility (Teffo et al., 2019). In collaboration with the Hasso Plattner School of Design Thinking[1] (HPSDT) at Cape Town University, workshops and seminars were conducted in which students from the University of Cape Town and the University of Oldenburg worked together to develop new ideas and approaches to address problems and challenges relating to water, energy, or mobility topics. One idea that emerged during the Summer School relates to the problem of mobility and aims to improve the daily commute to work for low- and middle-class workers, especially for those from outside of Cape Town. Based on the design thinking process by HPSDT, a new concept for a car-sharing platform was conceptualized, which aims to address the key problems of public transport in South Africa with regard to safety, availability, efficiency, and reliability. Furthermore, the solution intends to reduce the steadily increasing congestion problem in the city of Cape Town by reducing the number of vehicles on the road by effectively distributing people across cars, thereby also reducing inner-city carbon dioxide emissions at the same time.

The paper is structured as follows: First, the methodology and the different phases of the Design Thinking Process (DTP) will be explained. The DTP is used to illustrate how the concept of the car-sharing platform was developed, how the target group was identified, and what their key needs and requirements are for a mobility system. The individual phases of the DTP will then be used to answer specific questions. To identify the shortcomings of the current status of public transportation, the following approach was conducted:

1. Comparison of the current situation of public transport in South Africa with the characteristics of an ideal transport system based on Knupfer et al. (2018).

   Indicators will be identified that can be utilized to measure the quality of a transportation system. These indicators will then be applied to identify and interpret the current state of transport systems in South Africa. The comparison as well as the interpretation of these indicators lays the foundation for answering the following questions:

   (i). Which transportation system do people currently choose for their commute to work?
   (ii). What are the reasons for this selection?
   (iii). What other options are available?
   (iv). What are the current problems of transportation?

[1] http://www.dschool.uct.ac.za/home-21

Fig. 1 Design Thinking Process (Teffo et al., 2019)

This lays the foundation to identify the shortcomings of public transportation in South Africa, which will be used in the next step:

2. Derivation of concepts to address the central problems of public transport in South Africa.

The derived concepts are then collected and aggregated into an overall concept using the design thinking process, which resulted in the final design of the car-sharing platform elaborated in this paper. It is shown how concept differs from other car-sharing solutions. The subsequent conceptual prototyping shows how the use of the platform could look like and how the process of building driving communities via the platform is structured. Discussion of the results will be used to address points that could not be addressed during the Summer School during concept development.

2 Design Thinking

"Design Thinking is a holistic concept to design cognition and design learning that enables [...] to work successfully in multi-disciplinary teams and enact positive, design-led change in the world." It describes a problem-solving approach and deals with "everyday-life-problems," which are nonetheless difficult to solve. "[...] Design offers a concrete solution to a complex problem that is socially ambiguous and neither easy nor certain to comprehend [...]" and hence, focuses on the "[...] need to create ideas and find solutions (products, services, systems) for existing problems—solutions, which are viable and novel for the particular groups of users"(Rauth et al., 2010). In education, there are several institutions like the Stanford University d. school in Silicon Valley, the Hasso Plattner Institute of Design in Potsdam, or at the University of Cape Town that teach students with different educational backgrounds and disciplines to work in interdisciplinary teams and projects to create innovative solutions in different areas such as companies or non-profit organizations (Sándorová et al., 2020). Figure 1 shows the individual steps of the DTP, which will be used to describe the individual steps in more detail (Sándorová et al., 2020).

Empathize describes the phase in which a well-founded understanding of the needs and problems of the target group is built up. This is done through research, observation, or interviews with a corresponding target group (Sándorová et al., 2020). Based on the identified needs, a problem area is defined for which a new solution is sought. Orientation is provided by questions such as: "What is particularly important to the user in the area under consideration?" or "Where do they see potential deficiencies or potential for improvement ?" (Meinel & von Thienen, 2016). *Define* describes the phase in which a problem is defined based on the result of the previous phase. Here, the problem-space is narrowed down to such extent that precise and target group-oriented problem definitions can be formulated (Sándorová et al., 2020). Based on the formulated problems, the *Ideate* process aims to generate and develop different possible solutions, which are implemented as exemplary in the subsequent *Prototype* phase (Meinel & von Thienen, 2016). In the final *Test* phase, the developed prototype is evaluated in appropriate field tests and on the basis of observations and further interviews to eventually determine its suitability for solving the defined problem (Sándorová et al., 2020). During the Summer School, the first four steps of this process were performed. In the following, it will be presented how the concept of the car-sharing platform was developed during the Summer School based on the individual steps of the Design Thinking Process.

3 Empathize and Define

In the first step of the DTP, interviews should be conducted. Due to the limited time frame of the Summer School, both the questionnaire and the survey itself had to be completed within one day. The number of respondents and the number of different groups covered by the survey are hence limited and therefore only representative to a limited extent. The interviews were conducted face-to-face without a defined questionnaire and were limited to people of the campus of the University of Cape Town. The questions that were asked within these individual interviews were oriented around the following general questions:

1. What are the most important aspects and characteristics of a transport system?

The identified characteristics, on the other hand, are to be contrasted with the following questions:

2. What is the current mobility status in South Africa?
3. Which of the most important aspects of a transport system are satisfied by the current state of transportation in South Africa?

Due to the limited time, efforts were made to interview as many different groups as possible. The interviewed groups consisted of students, cleaners, bus drivers as well as cafeteria and security staff at the University of Cape Town. The interviews revealed that the daily commute to work, especially from outside Cape Town, poses a major challenge for every questioned group. Because the interviews provided only a limited problems of the current state of mobility including public transport, literature research was conducted based on the information obtained from the interviews to better understand the problem. The literature review will be further described in the following sections.

4 Most Important Characteristics of a Transport System

In their report, Knupfer et al. (2018) define and describe various indicators that can be used to evaluate the quality of transportation systems in selected cities around the world. By weighting the different indicators, a set of rules for calculating a mobility quality score was created. During indicator definition, the authors distinguished between indicators that occur before and after a respective trip.

Table 1 shows the different indicators developed by the authors. *Availability* refers to attributes such as the amount of coverage and access options of the considered area, the number of available stations, the distances between stations as well as other attributes such as the number of services offered during certain time periods, and the respective geographic location of stations (Eboli & Mazzulla, 2012). *Affordability* describes accessibility to transportation systems in terms of monetary costs (Knupfer et al., 2018). This is often mentioned in conjunction with the term cost-efficiency, which "[. . .] reflects the ratio of inputs (costs) to outputs (desired benefits)" (Eboli & Mazzulla, 2012). *Efficiency* includes factors such as the amount of time spent using the transportation system. These are characteristics like travel time, waiting time, or the time loss due to intense traffic congestion when using private vehicles or public transportation (Knupfer et al., 2018). *Convenience* relates to factors like comfort, cleanliness, or service reliability of the transportation system. This indicator includes factors like comfort, the ability of the respective transportation system to maintain schedule, or the assurance of regular trips at regular intervals. A consistent travel time and the physical condition of the transportation system are factors that are also included in *Convenience* (Eboli & Mazzulla, 2012). In their report, Knupfer et al. define the indicator *Sustainability* to include the property *Safety* in relation to possible traffic accidents and the environmental impact when using the transportation system, for example through the emission of pollutants. Eboli & Mazzulla, (2012) further extend the aspect of security to include "degree of safety" from crime and the perceived level of safety. *Safety* relates to the protection from crimes as well as the safety related to the behavior and activity of other persons that also use the transportation system. *Public perception* can be used as an indicator by measuring customer satisfaction when using the respective transport system (Knupfer et al., 2018).

As part of the report, Kupfer et al. conducted expert interviews and resident surveys to determine the most important aspects of transportation systems. The results show that both expert groups and residents consider *Safety* to be the most important aspect of transportation systems (Knupfer et al., 2018). Public transport *Efficiency* and *Affordability* are the second and third most important aspects, while

Table 1 Indicators to evaluate transportation systems (Knupfer et al., 2018)

Before the trip		After the trip
Availability	Efficiency	Sustainability
Affordability	Convenience	Public perception

the environmental impact in regard to *Sustainability* receives a slightly less importance (Knupfer et al., 2018).

Teffo et al. obtain similar results in their surveys and subsequent analyses. Based on surveys of different groups of people in different districts in Cape Town, the authors conclude that both personal safety in walking to or from public interchanges and the personal safety from crime are the most important considerations for people when choosing their public transportation mode (Teffo et al., 2019). *Availability* also plays a subordinate role for both experts and surveyed residents and is rated as moderately important by both groups. The report from Knupfer et al. also shows that one of the major cities in South Africa, Johannesburg, compares much worse with other cities in terms of efficiency and affordability. After identifying the indicators used to evaluate the quality of transportation systems, the question regarding the current state of transportation systems in South Africa will be answered.

5 Current State of Transportation Systems in South Africa

South Africa is subject to constantly evolving demographic changes, such as steadily increasing population growth and wealth distribution (Vanderschuren & Baufeldt, 2018). More and more people are moving into the middle class, which is continuously changing how and what transportation systems are used and needed (Vanderschuren & Baufeldt, 2018). The National Household Travel Survey (NHTS) of the Federal Highway administration indicates that more than 99.6% of surveyed private households own at least one vehicle, while 38.3% own two, 21.2% own three, and 9.7% even own 4 vehicles per household.[2] This is a drastic change compared to the results of the NHTS 2013, where only 28.5% of the household had access to private vehicles.[3] This leads, on the one hand, to the fact that streets and cities become more and more crowded and the number of traffic congestions increases (Vanderschuren & Baufeldt, 2018), on the other hand it also leads to the fact that more and more people are using their private vehicle to go to work and avoid public transport. The NHTS shows that 42.3% of trips were taken with a car, while only 1.4% used the public or commuter bus and only 2% used the commuter rail.[4] The data also shows that 50.9% of the trips taken are either work related trips or for the way homes.[5] The General Household Survey (GNS) 2019 amplifies these findings, showing that only 5.6% of the surveyed households used the bus or train to commute to work.[6]

[2] https://nhts.ornl.gov/vehicle-trips, Vehicles Available, last visit: 25.03.2021.

[3] https://www.statssa.gov.za/publications/P0320/P03202013.pdf, last visit: 25.03.2021.

[4] https://nhts.ornl.gov/person-trips, Transportation Mode, last visit: 25.03.2021.

[5] https://nhts.ornl.gov/vehicle-trips, Trip Purpose, last visit: 25.03.2021.

[6] http://www.statssa.gov.za/publications/P0318/P03182019.pdf, Page 54, last visit: 26.03.2021.

In terms of the working class, this creates two sides that need to be considered: The one side which is dependent on public transport systems because there are not enough private vehicles available, and the other side, which has enough private vehicles available and commutes to work by car. For both groups, different problems may arise during the commute to work that can potentially be analyzed in order to determine the current state of transportation.

In terms of public transportations, people have the options of commuting via the traditional commuter rail system, the commuter bus industry and the minibus-taxi industry (Walters, 2014). While buses and trains only account for 5.6% of the chosen transportation modes, the portion of minibus-taxis is 26.3% according to GNS 2019. The report also shows that 21.5% of the surveyed people do not use transportation at all and commute to work and back by walking. Accordingly, it can be stated that people who rely on public transport either walk or use the minibus-taxi as a means of public transport.

There are different reasons why the share of public transport is low compared to other transportation system, the most significant however can be attributed to the following indicator: *Safety*. Breetzke & Edelstein (2020) show that public transport interchanges such as bus or train stops may act as crime generators and state that these facilities are"criminogenic settings commonly targeted by offenders for crimes." Public transport interchanges are also often overcrowded and have a lack of police presence, while minibus-taxis often operate without licenses and in some cases, even with unlicensed drivers,[7] which further intensifies safety issues. Hitge & Vanderschuren (2015) show that because of these problems, people may be forced to take detours in order to safely get to their target destination: "The distance a person has to or is willing to walk, is influenced by the proximity of the nearest public transport, surface quality, lighting, safety and trip purpose" (Hitge & Vanderschuren, 2015). The authors also show that, at least in Cape Town, minibus-taxis are the most accessible and rail is the least accessible public transport mode, which further explains the data presented in the NHTS and GNS reports. Another factor to consider is that travel time is significantly higher when using public transportation in comparison with the time investment when using the car. The average distance of public transport trips are longer and the average speed with the car is also higher (Hitge & Vanderschuren, 2015). The lack of availability of travel information, inconsistent structure of schedules, frequent delays or cancellations, a lack of maintenance of stations as well as respective stops are other problems that further intensifies the overall problem of public transportation[7]. In summary, it can be stated that public transport is: unsafe, unreliable, poorly available, time-consuming, and inconvenient.

People who can drive to work in their private vehicles experience far fewer problems, as they are not affected by issues such as safety on public transport. However, due to the increasing number of vehicles on the roads, congestion and slow-moving traffic are becoming more frequent. The larger cities in South Africa

[7] https://www.saferspaces.org.za/understand/entry/the-state-of-public-transport-in-south-africa, last visit: 26.03.21.

are particularly affected by this, leading to a deterioration of parking space and an increased emission of pollutants within the cities.[8]

By answering the questions regarding the most important aspects of transport systems and analyzing the current state of transport systems, it was possible to further narrow down the target group considered during the Summer School: Groups that rely on public transportation the most face the most difficult problems when commuting to work, which is why they are the target group around which a solution should be found. A comparison of the indicators used to assess the quality of a transport system and the current state of public transport in South Africa shows that none of the identified indicators that define an ideal transport system are in a positive condition. The most important indicator, *safety*, cannot be guaranteed in any of the public transport choices, both within the transport system and outside of it, such as at bus stops. While Teffo et al. (2019) show that indicators such as *Efficiency*, *Availability*, *Affordability*, and *Convenience* play a subordinate role in how people choose the transportation mode, they are also nonetheless unable to be met by the current standard of public transport.

By comparing the current state of public transport and the needs of its users, it was possible to uncover the discrepancies that served as the basis to specify a concrete problem-space for the *Define* phase of the DTP. The core problem that should be fixed is giving people a safe alternative to commute to and work and back. Characteristics such as *Efficiency*, *Availability,* or *Convenience* should also be considered, but play a subordinate role in comparison with *Safety*. In the following *Ideate* & *Prototype* phase, it will be described how the concept of the car-sharing platform was developed based on the identified and defined problems.

6 Ideate and Prototype

Looking at the rising number of private vehicles on the streets and the rising numbers of trips with private cars, car- and ridesharing appear to be potentially promising concepts to address the described problems. Vanderschuren & Baufeldt, (2018) examine the potential for utilizing ride sharing in developing cities like Cape Town and the potential benefits it can provide. The authors see the potential of ride sharing markets primarily in occasional short trips such as shopping trips or for accessing to medical, welfare, or financial services (Vanderschuren & Baufeldt, 2018). The potential target group for this type of service appears to be primarily the low and middle income group, while groups with higher incomes would use platforms such as Uber (Vanderschuren & Baufeldt, 2018). However, the authors also describe that under current circumstances, commercial car-sharing is not

[8] https://acceleratecapetown.co.za/cape-towns-mobility-crisis-potential-influence-corporate-sector/, last visit: 27.03.2021.

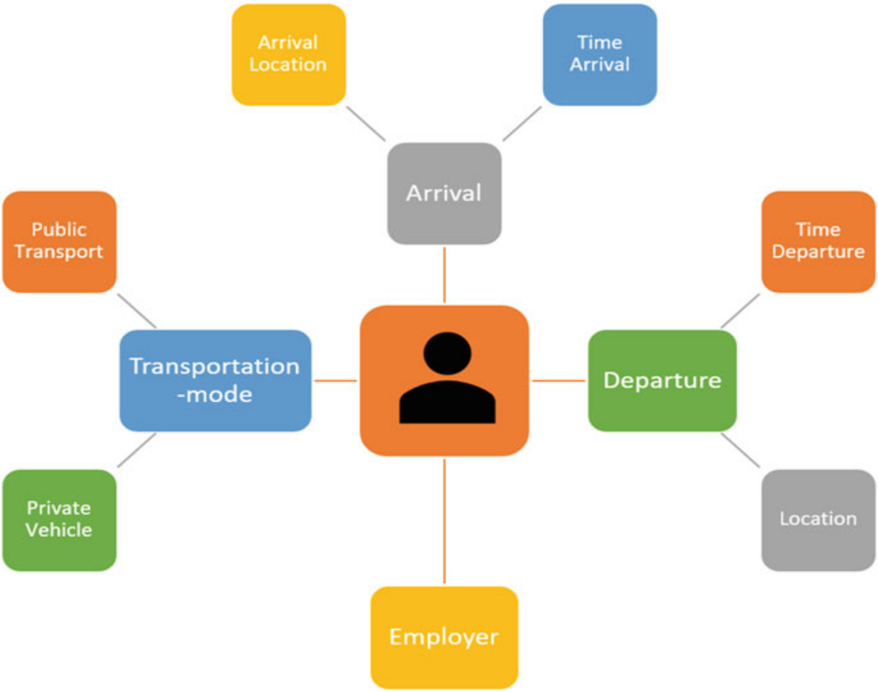


Fig. 2 Characteristics of the commute to work

suitable for commutes to school or work, but rather for short and spontaneous trips lasting less than 15 minutes (Vanderschuren & Baufeldt, 2018).

A brainstorming session was conducted to elaborate and summarize characteristics of a general commute at an "individual person" level. The results of this process can be seen in Fig. 2. The figure describes characteristics that each individual person has with regard to their commute. Each individual person has a starting point and a destination point for their commute, each of these points has a specific location and a specific time or time frame. Furthermore, each person has the choice between the available transport systems, which in this case are either the private vehicle or public transport. Another common characteristic, which was completely overlooked at first, is that each person has an employer to whom they commute to work. Destination and origin of the commute are therefore, with respect to the route to work, always predetermined and ideally remain constant over a long period of time. Looking at other ridesharing services such as Uber or Taxify, these services specialize in providing spontaneous short trips from different locations to different destinations. In the case of Uber and Taxify, the characteristics *Arrival* and *Departure* become dynamic entities that change frequently depending on where the service is used and what the destination is. In the case of the commute to work however, these properties become non-dynamic and in principle do not change frequently, since the departure point is most likely their home, and the destination is their workplace. Furthermore, it was observed that currently none of the established car sharing services in South Africa like Uber or Taxify considers the employer criterion in the design or operation of their respective platforms. When asked whether there is a potential intersection of people whose starting and ending points are the same in terms of *Location* and *Time* as well as non-dynamic and whose choice and availability of *Transportation Mode* are different, the idea of adopting the *Employer* as a central element in the creation of the car-sharing concept emerged.

7 The Car-Sharing Concept

At its core, the concept, just like similar services in South Africa, is a platform to share mobility resources. The fundamental difference, however, is that the concept was created and elaborated entirely around the entity *Employer*. The idea is to partner with businesses and companies in urban areas or places with a high number of businesses in one spot, who then give their employees the ability to sign up on a platform to create driving communities. In Fig. 3, the basic concepts of the platform can be seen. On the left side are the companies and corporations that established a partnership with the platform. These companies have a varying number of employees and different company locations. On the other side are the users of the platform, who are associated with a company, have different places of residence, and can therefore be assigned to different districts or parts of the city. The goal is to form consistent driving communities between users by matching those who live in approximate to each other and are employed at the same company or at companies that are in approximate to each other.

To guarantee a safe environment for building driving communities between users, people can only register and access the platform when they are currently employed at a company which has established a partnership with the platform. This way, the

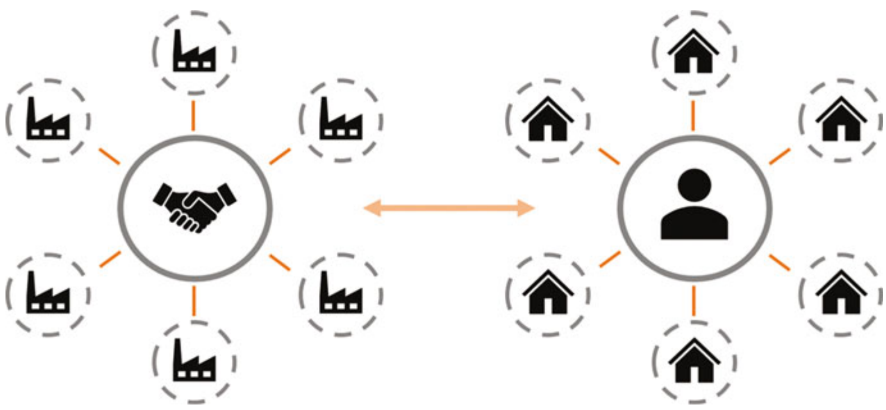


Fig. 3 Concept of the car-sharing platform

identity of every user can be always assured and in case of problems, the identity of the person can always be traced back to the employer. The actual formation of driving communities is done by matching registered users who own a car with users who do not own a car, based on the geographical constraints *Departure*, *Arrival,* and company location. The distinction between users who own a car and those who do not is a central aspect of the platform and largely determines the way in which one interacts with the platform. To illustrate this, several mock-ups were created to show how users potentially interact with the platform and how the process of forming driving communities would work.

8 Conceptual Prototyping

In operation, the user's interaction with the platform would be via an app on the smartphone or the computer. For this reason, conceptual prototypes in the form of mock-ups were developed during the Summer School to describe the user experience, the registration process, and the carpooling process. The registration process can be seen in Fig. 4. Here, all data required for the successful registration of the user can be seen. In addition to classic metadata such as the name, email, telephone number, and address, the user is also asked to give the name of his current employer. When the company name is submitted, the system then checks whether the information provided matches the platform's internal information or not. The registration process can only be completed once there is a match when cross-checking the personal information provided and the employee information provided by respective partners. Another important specification is whether the user wants to register as a driver or a normal user. When registering as a driver, a check of the vehicle information data would take place at this point, but this is not considered further in the prototyping process. Depending on whether the user has registered as a driver or not, this has an impact on the user experience and how the user interacts with the app. Drivers, for example, have access to functionalities that a normal user would not have.

The central goal of the platform is to match these two types of users based on their metadata, such as location and employer, to form driving communities. The application therefore needs to have the functionality to effectively enable the consolidation of users and drivers and provide the functionality for the drivers to eventually manage administrative tasks regarding their driving community. The following section shows the process of how standard users as well as drivers can connect with each other via the platform as well as the description of the essential differences in functionality and user experience between a driver and a user.

Connection Process for Users Once the account creation has been finished, the user will be transferred to the main page, seen in Fig. 5. In the top left corner is a menu bar with offers the user some essential functionalities, which will be described later. Under the menu tap is a search bar, which the user can use to manually search

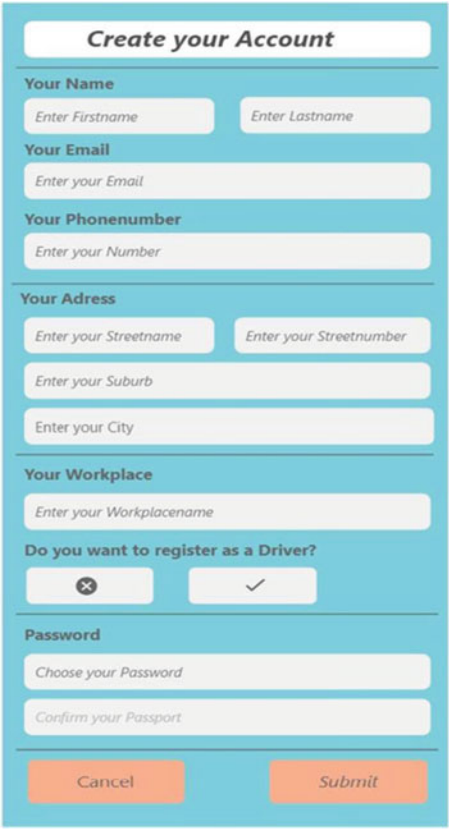


Fig. 4 Account creation

for specific locations. The application requires that the transmission of location data of the device to be activated. This way the service can automatically assign the user to his current location and show other users in the surrounding area. The map in the center of the screen displays this functionality. Each mark on this map represents another user. There are two different types of marks. One which is blank and one with an additional car symbol. The car symbol in the bottom right corner of the respective mark gives the user visual feedback that this particular mark represents a driver who has free seats left on which the user can apply on. To do that, the user needs to interact with the mark by tapping on it. The result of this step can be seen in Fig. 6 in the additional detail window. The user now receives specific information about the respective driver like the name, a profile picture, and a rating score. The implementation of a rating system, in which users can rate other users, should enable the platform to be a friendly and healthy environment and should reward users as well as drivers for positive behavior. By pressing *Show Details*, the user furthermore receives additional information about the respective driver, which can be seen in the bottom of the main screen. To complete the process of connecting with other users, the user has to send a request to the respective driver by pressing *Send Request*. The

Fig. 5 Main Page

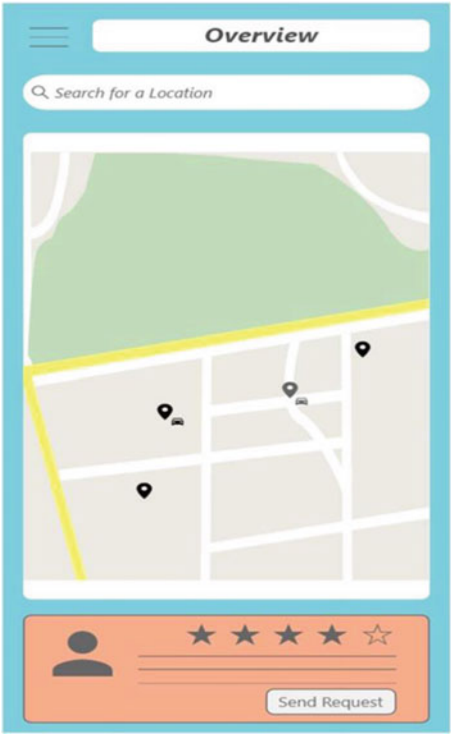
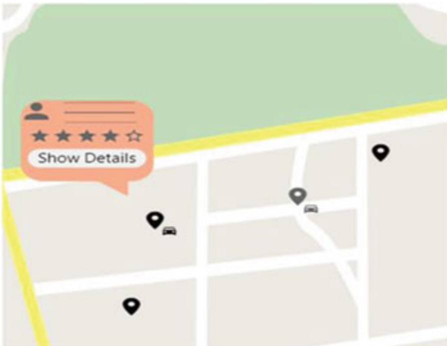


Fig. 6 Driver Details



overall process of connecting users is not quite finished yet, the driver still has to accept the corresponding request to finalize the process. What follows now is the description of how drivers would interact with the application and how they can manage administrative tasks like the handling of received requests.

User Experience for a Driver The main screen for a user that has registered as a driver, seen in Fig. 7, differs from the main screen of a standard user in regard to aspects like layout and functionality. In the center of the screen, there is a section in

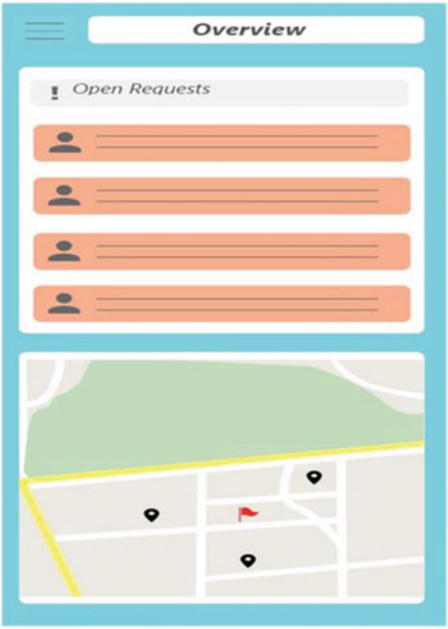
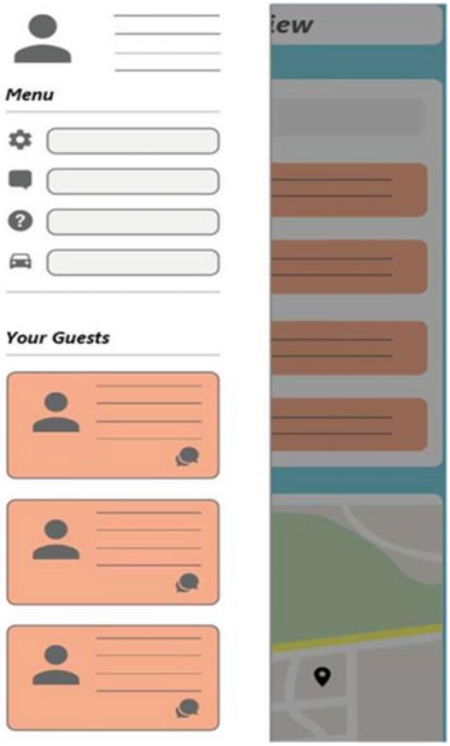


Fig. 7 Driver Screen

which all the received, but unanswered requests of other users are listed. Beneath that, there is a map which displays the location of the other users who already occupied a seat in the respective car of that driver. The red flag in the center of the three marks represents a suggested pick-up location, where the group can meet to eventually commute to work together. Other than the standard user, the driver needs to have the additional features and functionalities to manage everything around the existing driving community. By pressing the menu bar in the top left corner of the screen, a menu unfolds, which can be seen in Fig. 8. In this menu, the driver has access to different options. The driver can customize his profile, has access to the settings, can write and read messages, there is Q&A section to reach out to the support and the driver can manage the information about the registered car. Besides that, the driver is shown information about his current passengers. This includes their profile card with specific information about every passenger, like name, address, and the profile picture. By pressing the message icon on the profile card, the driver can directly message them if needed. Looking back to *Open Requests* of the *Driver Screen*, each bar represents a user who applied for an unoccupied seat in the car. The bar displays the profile picture of the corresponding user and essential metadata like name and address. The driver can interact with these bars the same way he can interact with the profile cards in the *Menu Screen*. By pressing on a particular bar, the driver receives additional information in a pop-up window, which enables the driver to furthermore interact with the corresponding user, seen in Fig. 9. Same as in the managing of current passengers, the driver has the option to message the other user. The driver now must evaluate if he wants to give this user the remaining seat and

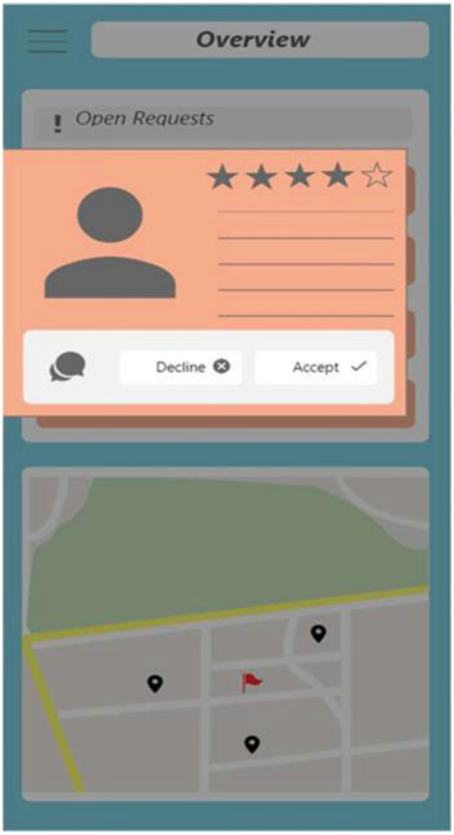
Fig. 8 Driver Menu Screen



accepts the request or if he wants to decline. Basis for this decision could be the rating score of the user, which is also displayed in this separate window. By accepting the request, the process of connecting user and driver is completed and further processes will be initiated. The other passengers will be informed about the new guest, the map in the drive screen will be updated with an additional mark that represents the location of recently joined guest. The suggested pick-up location will also be newly calculated and rearranged.

This completes the prototyping that was done during the Summer School. The process of registering drivers and normal users as well as the process of connecting both groups was conceptualized. The elaborated and completed phases of the Design Thinking Process are also completed, as a technical implementation or a technical prototyping was not possible due to time limitations during the Summer School. In the following, the results as well as the concept of the car-sharing approach will now be discussed.

Fig. 9 Request Details



9 Discussion

Due to the time constraints during the Summer School, some aspects could not be considered when conceptualizing the car sharing platform. On the one hand, legal aspects such as the insurance of the vehicle, drivers and passengers or the verification of the driver's license and vehicle documents were not considered, and on the other hand, no market analysis was carried out to determine whether it is in the interest of the companies and firms to be participants in such a platform in general. In addition, there are still unanswered questions regarding the problem of not having enough drivers or free seats in the area to meet transportation needs. These points would have to be examined more precisely in more in-depth studies and requirements analyses to ensure the viability of this concept. It was also not possible to work on a potential payment model during the Summer School. This raises the questions of how, for example, drivers are paid for providing their vehicles, how much passengers eventually pay for the service, how this price is calculated, and how the actual platform generates revenue. A commission model could be considered here, but at the same time it would have to be ensured that the service is still competitive compared to other services.

10 Conclusion

In this paper, a new car-sharing concept was presented, which was developed during the HEdIS Summer School 2018. By contrasting the current state of transport systems in Cape Town and the needs and key indicators of transport systems for users, a concept was developed that addresses the key problems of public transport and differs from other car sharing services by involving the employer in the platform. The platform aims to provide workers with a safe alternative to get to and from work, while reducing traffic congestion on the roads and in the city through the formation of consistent carpools. Aspects that could not be considered during the Summer School, such as legal framework conditions or a general market analysis in the form of determining the general acceptance or interest of employers in such solutions, could be further explored in the future.

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A Framework for Social Urban Water Management

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Abstract Water demands have grown and become more diverse in the twenty-first century. Subsequently, sustainability has become an important topic globally, socially and sustainability of water is important for communities to have access to reliable and safer water sources. Water management is important for the economy and population growth of developing nations. Issues such as water accessibility, household water management are challenges that have increased water demand in developing economies. Information and Communication Technologies (ICTs) are deemed to be drivers that can improve the sustainability of water management in urban areas. The study aims to propose a theoretical framework that can be used to investigate the factors of sustainable urban water management.

The Systematic Literature Review (SLR) approach was deemed as relevant to investigate sustainable urban water management. Additionally, the study used the SLR to find the different theories used in sustainability under urban water management. The SLR applied one literature source ScienceDirect and several databases within the database. The findings of the SLR were analyzed using graphs, counts, and text analysis of the data. Using the text analysis, the SLR results confirmed that the articles screened through the process fitted the study as they focused on sustainability, water management, and within the African context.

Thirty-one articles were the results of the SLR process which were synthesized for the study. The SLR results discovered that one study applied theories in addressing sustainability issues within urban water management. The study underpins the proposed theoretical framework on the philosophy of the socio-technical system. The framework was based on the social aspect of sustainability focusing on factors, namely, ICT, accessibility, and urban water management. The theoretical framework is the contribution of the study, as it proposes key elements that should be addressed to improve sustainability in urban water management.

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Keywords Accessibility · ICTs · Urbanization · Urban Water Management · Sustainability · Theory

1 Introduction

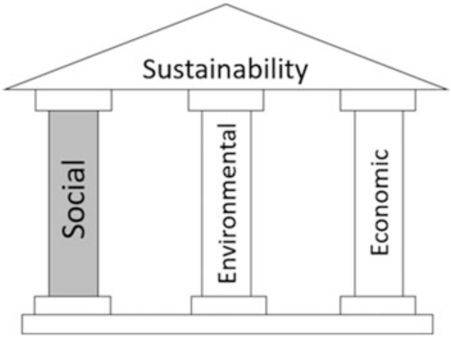
Water sustainability has gained importance as a key requirement to protect future generations' access to reliable and safer water resources, therefore, addressing Goal 6 of the Sustainable Development Goals (SDGs) (United Nations, 2016). Momblanch et al. (2019) further argue that water demands have grown and become more diverse due to rapid human movement making water resource management more complex. Li et al. (2019) purport that on the top five key risks globally over the years water scarcity is included. Additionally, water is important for the economy, and population growth, increased food demand, and fuels have raised concerns about the scarcity of freshwater resources and unsustainable practices worldwide (Li et al., 2019). In support, Zafirakou (2017) adds that water is critical for socio-economic development and the viability of ecosystems. Economy and Society are key pillars of sustainability as sustainability is the guiding principle and goal for human and economic development.

The sustainability of urban water management is a critical concern in the twenty-first century (Milman & Short, 2008). Loucks and van Beek (2017) define urban water management as involving the planning, design, and operation of infrastructure needed to meet the demands for drinking water and sanitation. Furthermore, the control of infiltration and stormwater runoff, and for recreational parks and the maintenance of urban ecosystems (Loucks & van Beek, 2017). As urban areas grow, so do the demands for such services. In addition, there is an increasing need to make urban water systems more resilient to climate change (Loucks & van Beek, 2017). Finally, socio-technical systems such as urban water management systems are key to adapting and predicting climate change and making cities achieve resilience (Brown & Farrelly, 2008).

The sustainability of urban water management is a critical concern even in South Africa, a country with a serious water shortage, there have been on-going studies under sustainable water (South African Cities Network, 2021). Additionally, countries such as Australia have been studying the challenges of urban water management in their cities (Brown & Keath, 2015; Van de Meene et al., 2011). The lack of understanding of urban water management can pose a serious challenge to sustainable development, however, when managed efficiently and equitably, urban water management can play a key enabling role in strengthening the resilience of social, economic, and environmental as pillars of sustainability as shown in Fig. 1 (Zafirakou, 2017). Due to the scope of the research, the study focuses on the Social pillar of sustainability. However, subsequent papers will focus on the Environmental and Economic pillars of sustainability.

Social—Social sustainability is defined as the development that meets the needs of the present without compromising the ability of future generations who meet their own needs (WCED, 1987). Additionally, social sustainability encompasses ideas of

Fig. 1 Sustainability Pillars



equity empowerment and institutional stability. Furthermore, social sustainability preserves the environment through economic growth (Basiago, 1998). Vallance et al. (2011) state that social sustainability includes a concern for a broad spectrum of issues ranging from tanging to issues like water. In support, Bramley and Power (2009) argue that the concept entails individuals within society working together and interacting to achieve socially sustainable communities.

Brown and Keath (2015) argue that social concerns such as resistance to innovation and limited community engagement arising from conventional water management approaches have prompted discourses such as SUWM (Sustainable Urban Water Management). SUWM is challenging due to limits in governance, including institutional inactivity and disintegration; an absence of professional and organizational capacity and failure to adopt new practices (Brown & Farrelly, 2008).

Economic—From the economic perspective, water scarcity impacts arise when the challenge of obtaining water forces a needy adaptation in water consumption. Additionally, global water scarcity/shortage/crisis is considered a leading challenge for continued socio-economic development and the achievement of sustainable development goals (Dolan et al., 2021). The expansion of economic and business activities including industrialization in recent decades exacerbated the problem of water scarcity and increased conflicts and political tensions, which highlight the need for sustainable development (Aznar-Sánchez et al., 2020). Water resources are subject to severe degradation due to multiple factors such as population growth, changes in land use, agricultural and urban expansion, and overexploitation because of economic development (Zhang et al., 2017).

Sustainable Development Goals call for ensuring the availability and sustainable management of water and sanitation for all by 2030. But water's significance goes further (United Nations, 2016). Furthermore, Molinos-Senante and Donoso (2016) state that water pricing is one mechanism of economic policy instruments that could be used to affect the environmental, social, and economic efficiency of water usage. Furthermore, the authors argue that water tariffs can take different forms in which each form seeks to address a specific objective. In general, these objectives address (1) economic efficiency, (2) water conservation incentives, (3) equality, and (4) affordability. With regard to water pricing, willingness to pay (WTP) has been reviewed as a contributing factor for supporting urban water sustainability. Adams and Vásquez (2019) state that the urban poor residential communities are unwilling to pay for water, while others argue that the urban poor is willing to pay at a reasonable price.

Environmental—These are solid waste treatment, wastewater treatment, flood risk, water scarcity, and urban heat islands challenges (Koop et al., 2019). Australia faces challenges similar to the global issues and increases in urban population, ageing, and degraded water infrastructures which influence a sustainable urban water supply. Other challenges are drought predictions and flooding which also impact the sustainable water supply. Urban areas have challenges with water and it is noted that there are five main water challenges for urban areas. These are solid waste treatment, wastewater treatment, flood risk, water scarcity, and urban heat islands challenges (Koop et al., 2019).

Sustainable urban water management is neither absolute nor a constant, sustainability must be considered as a dynamic concept, which will change over time in a place. Therefore, maintaining and increasing the percentage of the population with access to water ensures the sustainability of urban water (Farrelly & Brown, 2011). This paper investigates factors within the social factor of sustainable urban water management using the following research questions to examine the phenomena:

- RQ1—What factors influence social sustainable urban water management?
- RQ2—What theories are used to address socially sustainable urban water management?
- RQ3—How can a framework be developed for sustainable urban water management societies?

Section 2 of the paper discusses the study's aims, Sect. 3 introduces the Systematic Literature Review method which is undertaken on the study. Section 4 focuses on the theoretical framework followed by Sect. 5, which discusses the contributions of the paper. Section 6 discusses recommendations and finally, Sect. 7 concludes the paper.

2 Aims of the Paper

The primary aim of this study is to develop a framework to address social sustainable urban water management. To support the main aim, a secondary aim is to find theories for developing the framework to address social urban water management.

3 Method Systematic Literature Review

The Systematic Literature Review (SLR) is a well-defined methodology that uses secondary data, the process provides a list of published studies relating to a particular subject (Wahono, 2016). In support, Kitchenham et al. (2007) state that an SLR

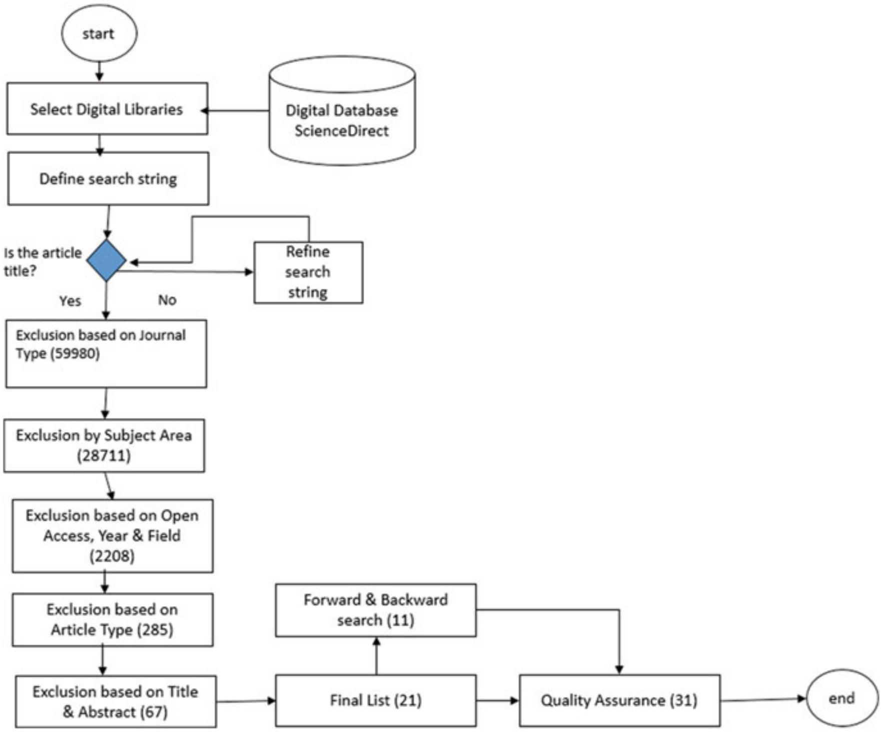


Fig. 2 SLR process adapted from Wahono (2016)

(1) summarizes existing evidence, (2) identifies limitations and benefits in the current literature, (3) identifies gaps and areas of limitations in the current literature. Finally, the SLR provides a framework to position new research activities.

This paper uses the SLR method (1) to investigate the literature under the social pillar of sustainability, additionally the SLR investigated facts of urban management water management. (2) the SLR was used to spot gaps in the current literature methods and theories applied in social urban water management research. Finally, the SLR was used to develop the theoretical framework.

According to Kitchenham et al. (2007), the SLR process consists of four steps, namely planning, selection, extraction, and execution, the research paper will follow the process prescribed by Kitchenham et al. (2007). Figure 2 depicts the process followed for the SLR.

3.1 Planning

The planning phase focuses on the protocols and the primary purpose of the SLR. The primary focus of the SLR is to answer RQ1—What factors influence social sustainable urban water management? and RQ2—What theory can be used to address socially sustainable urban water management? The SLR is conducted by 4 researchers and therefore a protocol for the SLR was devised and agreed upon.

A search string was developed and tested as *"Sustainable urban water management,"* the focus was on the titles that contained words regardless of field (social, economic, and environmental). The search string was tested as to fitness to ensure that it yielded accurate results.

3.2 Selection

The selection process is searching for articles (Kitchenham et al., 2007). Petticrew and Roberts (2006) argue that there is a massive amount available on a specific subject. To produce high-quality research a qualified information scientist must be consulted. On the contrary, Petticrew and Roberts (2006) argue that as long a rigorous process is followed on finding the literature the quality can be attained.

For this study, the selection was undertaken with a conscious decision of consulting only one database, the ScienceDirect. The ScienceDirect database covers a wide range of journals from science, life sciences, social sciences, and humanities.

Subsequently, the research team decided the database will yield satisfactory results as the number of journals was sufficient: Science of Total Environment, Sustainable Cities & Society, Procedia—Social and Behavioral Sciences, Ecosystem Services and Ecological Economics. The search was refined based on Subject Area: Environmental Sciences, Social Sciences, Economics, Econometrics & Finances.

In summary, the selection process focused on the Year of Publication: 2017–2021, the Publication Types: Research Article with Open Access, Search string: Social Sustainable AND Urban OR Water AND Management, Selected Studies resulted in 285 articles which the title closely matched the search string. The exclusion criteria were applied based on the Title and the Abstract which resulted in 67 articles.

3.3 Extraction

The general inclusion/exclusion criteria are considered critical to assess the quality of the SLR (Kitchenham et al., 2007). In addition, Wahono (2016) states that quality assurance must be undertaken as it provides more detailed inclusion/exclusion criteria and it is further used to guide recommendations for further research. The quality assurance checklist was designed to include questions that addressed the issues that the research team viewed as important in the literature. The following questions were used for quality assurance:

- Does the study have a methodology? If so, what is the methodology?
- Does the study have a theory? If so, which theory?
- Does the study address the factors of social sustainable urban water management?
- Does the study address water accessibility in social sustainable urban water management?
- Does the study address ICT in social sustainable urban water management?
- Does the study address household water management in social sustainable urban water management?

The quality checks and the review data were included in the same form, the research group reviewed the articles and settled any conflicts they had. Kitchenham et al. (2007) argue that in assessing the quality of the selected studies inclusion and exclusion are used and Execution will be undertaken as it will present collating and summarizing the results. Finally, the findings will be synthesized.

3.4 Execution

Data execution is the last step of the SLR process which involves analysis of findings and synthesis of findings (Kitchenham et al., 2007). Data Synthesis involves collating and summarizing the results, graphs and tables can be used to present the results.

The final SLR results included 31 journal articles that met the SLR's inclusion and quality assurance criteria. Figure 3 shows the title themes of the articles that were text analyzed and most of the titles had words on water, sustainable, urban, and management as mostly appearing words on the titles. The context of the titles focused on Africa, South, and Sub-Sahara. Therefore, titles focused on the themes of this research paper.

Fig. 3 Title cloud analysis

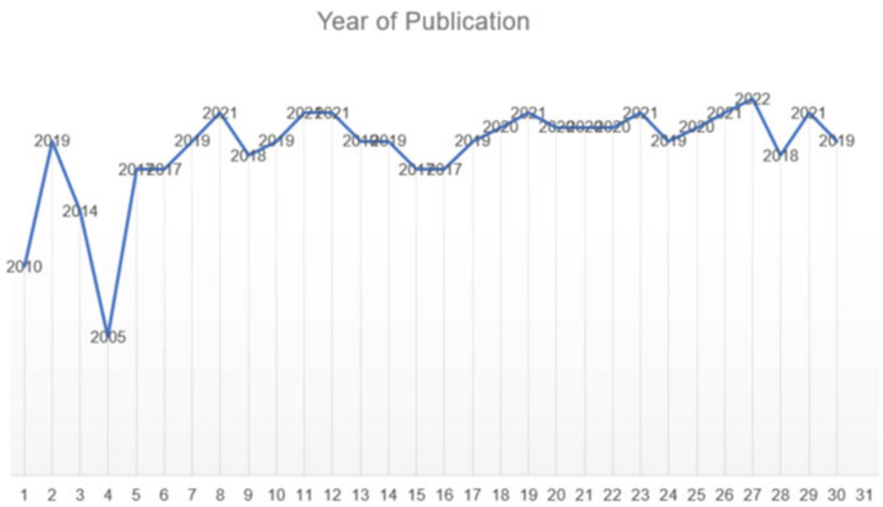


Fig. 4 Years of publications

Table 1 Methodologies applied in SLR studies

Methodology	Article	References
Case study	8	Apostolaki et al. (2019), Cremades et al. (2021), Earle (2015), Etxano and Villalba-eguiluz (2021), Herslund and Mguni (2019), Meza et al. (2021), Omar et al. (2017), Ziervogel et al. (2010)
Interviews	2	Ndeketeya and Dundu (2019), Wrisdale et al. (2017)
Mixed methods	4	Hegarty et al. (2021), Koop et al. (2019), Mondejar et al. (2021) Salmoral et al. (2020)
Surveys	1	Vollmer et al. (2018)
Qualitative analysis method	1	Campos and Marín-gonzález (2020)

The articles were analyzed based on the year of publications, most articles were published in the years 2019 and 2021 as shown in Fig. 4. An exception of articles published in 2005 was retrieved through the backward and forward search of the SLR process.

The methods/methodologies applied in the articles study were investigated with 16 articles as indicated in Table 1 including some form of research methodologies in their approach while nine studies did not have methodologies discussed in detail.

The above table shows the results on the methodologies applied in the studies, eight case study approaches are used in the studies, followed by four mixed methods studies. One study used a Systematic Literature Review approach in assessing the economic solutions used in water systems.

3.5 Literature Synthesis

The synthesis of the SLR is based on the research questions or the purpose of the SLR. Research question *RQ1—What factors influence social sustainable urban water management? and RQ2—What theories can be used to address socially sustainable urban water management*? The synthesis focuses on the factors discovered through literature and theories used in social urban water management.

3.5.1 Factors Synthesis: Water Accessibility

Water Accessibility (WA) is a topic relating to the supply of the water intake point, the distance from the water consumption grid to the water intake point, and the location distance of the water consumption grid (Li et al., 2019). There are many WA definitions; however, these are the factors considered when defining WA, the distance, quantity, source, and time (Aikowe & Mazancová, 2021). While the concern is with WA's definition, it is noted that water is hard to find as a valuable natural resource. Life for humans revolves around the availability and accessibility of water subsequently, conditions of living and standards in any human settlement are defined by the availability and accessibility of water (Muzondi, 2014).

Access to water is a major issue in many locations around the world, it is reported that over two-thirds of the world's population is living in water-stressed areas (Bollinger et al., 2018). Additionally, Ziervogel et al. (2010) argue that there is an anxiety about the access, availability, and quality of water resources in Africa because of climate change (Ziervogel et al., 2010). Challenges to water availability and access, as well as the conservation of the green areas of the city and traditional urban farmland are prevalent (Salmoral et al., 2020). In South Africa, the Western Cape Province experienced drought for three years (during 2016–2018), which led to thousands of middle-class homes mounting rainwater tanks in their homes (Ndeketeya & Dundu, 2019). Climate change and drought have posed challenges in water accessibility; however, rainwater tanks have proved to be a sustainable water source in cities in Western Cape.

Ndeketeya and Dundu (2019) presented two distinct aspects of water accessibility: the consumer and the service providers' perspectives. The consumer's perspective focuses on the level of satisfaction with the water provision system in place and has an impact on people's willingness to pay for an improved service. Meza et al. (2021) consider access to the water source, the water availability as consumer perspectives. While the service provider focuses on infrastructure to provide water to consumers (Ndeketeya & Dundu, 2019).

However, the service provider faces several challenges to supply water to consumers, usage of old water systems still being instead of using new water systems (Earle, 2015). The old water networks must be modernized, as old water systems account for a significant amount of water lost. Water lost to leakages is at 25% of total water consumption. Sometimes water loss is attributed to obsolete and ailing infrastructure, water tariffs that do not cover expenses and entities that face significant technical, financial, and management challenges (Agri-Orbit, 2020).

Additionally, challenges such as poor management skills of urban water while there is an increasing demand in water supplies. Therefore, urban water management skills are foreseen as the major focus of urban water agencies over the next several years to come (Brelsford & Abbott, 2017). Finally, drinking water project demands are based on contradictory expectations about population growth and living standard changes (Momblanch et al., 2019).

3.5.2 Factors Synthesis: Urban Water Management Household Usage

There is intense pressure on the water supply in South Africa as the demand is rising continuously. The goal of the Acts 1997 National Water Services Act (RSA, 1997) and the National Water Act of 1998 (RSA, 1998) is to ensure the right of access to basic water supply, within 200 m of the household, 25 liters per person per day. Other studies conducted show that between 157.2–300 liters of water are consumed by a person per day (Pullinger et al., 2013; Willis et al., 2013). However, the household consumption is three times higher when compared to 50 liters per person/per day which is the estimated consumption by the USA and the South African recommended daily consumption of 50 liters per person/per day (Gleick, 1996).

Jacobs-Mata et al. (2018) argue that to reduce water consumption in households, there must be existing household water usage understanding, water use perceptions, and what drives the water use behavior of households. Willis et al. (2013) add that several socio-demographic factors can influence water consumption in households, namely owner-occupied properties, higher-income families, and households with swimming pools that consumed more water. However, Pullinger et al. (2013) disagree as they state that socio-demographic variables weakly predict household consumption. To understand household water consumption, socio-demographics must be investigated and understood.

People must know how much water they use for different daily household activities. They should know effective behavioral changes when it comes to conserving water. It is also important to know what motivates people to use water the way they do and how they can be persuaded to change those ways (Jacobs-Mata et al., 2018). In support, Pullinger et al. (2013) state that a practice-based approach focuses on the routines and habits of everyday life through which water is consumed. The practices further show attitudes and values that can help in managing water demands. Subsequently, water demand management in the household provides benefits to the entire water sustainability (Willis et al., 2013).

Alleviating water demands can be achieved by a change in water consumption behaviors in households (Koop et al., 2019). With continued drought prevalence there is a need for critical water conservation measures, which will aim to influence consumers' behavior to enforce a sustainable water future for all (Hammond et al., 2022). Additionally, Pullinger et al., (2013) argue that innovative interventions would enhance understanding of consumer behaviors which can improve sustainable urban water.

3.5.3 Factors Synthesis: ICT Synthesis

Water management in urban areas has become a critical and complex task for water stakeholders such as managers, which goes beyond the supply of safe drinking water for households' activities. The on-going urbanization, industrialization, and other related water threats exacerbate challenges on the shared water resources and consumption, which impact the core urban sustainability growth (Laspidou, 2014). Further, to meet these challenges and to be able to drive sustainable urban socio-economic growth, cities need to become smart and tap their innovation potential through the adoption and usage of Information and Communication Technologies (ICTs).

Laspidou (2014) argues that leveraging the power of ICTs for innovative water management is the positive initiative in the right direction. For example, Integrated Water Resources Management (IWRM) is rising due to innovative technological advances, which have expanded the water management scope to cover entire water river basins, including the sustainability of ecosystems, economic and social welfare (Choi et al., 2016). In support, Byeon et al. (2015) agree that ICT solutions can play a key role in implementing the concepts of IWRM and achieving urban water sustainability.

Capacity development has been argued as one of the strategies for enhancing the sustainability of natural resources consumption. Kunjuzwa et al. (2020) posit that appropriate ICTs such as social computing technologies can be used as instrumental enablers for knowledge capacitating and raising awareness of water resource issues (water usage and conservation). ICTs are frontline tools for all investments that can enhance the frontiers of knowledge and skills for sustainable development and human well-being (Okaka & Apil, 2013). ICT can assist water managers to drive purposeful information campaigns and integrate the water sector with other city services, to deliver sustainable services and enhance the quality of urban life (Laspidou, 2014).

Sustainable Urban Water Management is possible and ICT solutions grounded on theories can further help to develop conceptual frameworks which can play a key role in the water challenges. It is hoped that the solutions will be employed by urban water strategists to help inform the development of more targeted and effective policy design and tool selection (Brown & Keath, 2015). A well-integrated ICT framework tool can play a significant role in sustainable development not only on the current urban water challenges but also in satisfying future generations' social needs.

ICTs have been widely adopted in the management of water and an array of applications have been presented to demonstrate water use efficiency with notable benefits (Hamdy, 2015). These benefits are:

- Real-time monitoring—water utilities can improve the demand response and reduce water losses within the water distribution system.
- Public engagement—ICTs can improve communication between water utilities and the public, which will lead to an increase in public awareness concerning consumption and water usage.

With the positive advancement of ICTs presented above, however, there has been little interest in most under-developed and/or developing economies in the subject of advanced technologies, mainly because advanced technology costs are perceived as unaffordable (Boyle et al., 2013). The lack of economic power within developing economies presents research opportunities for the development of cost-effective ICT-integrated solutions, which can enhance sustainable urban societal growth.

4 Theoretical Framework

The SLR revealed a lack of theories in addressing sustainable urban water management as there was only one theory, the social movement theory. An in-depth review in search of relevant theories for our proposed framework was undertaken. The socio-technical systems theory was deemed relevant (Fig. 5) for theoretically grounding our proposed framework. The socio-technical systems theory was established to emphasize the reciprocal interrelationship between humans (citizens) and machines (technologies). To strengthen the shaping of both the technical and the social aspects, in such a way that efficiency and humanity would not contradict each other (Ropohl, 1999).

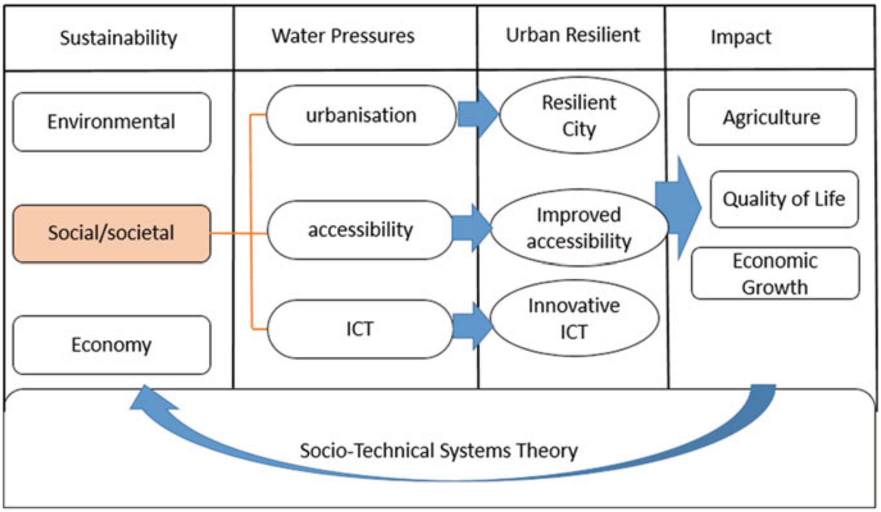


Fig. 5 Social Urban Water Management Framework adapted from Apostolaki et al. (2019)

Socio-technical systems theory is the most extensive body of conceptual and empirical underlying work for application design (Applebaum, 1997). The adoption of a socio-technical systems theory approach to system development leads to systems that are more acceptable to consumers (citizens) and deliver better value to stakeholders (water suppliers) (Baxter & Sommerville, 2011). Furthermore, the socio-technical system theory design considers human, social, and organizational factors. We deduce that the philosophy of socio-technical systems is a "*lens*" for designing a conceptual framework for sustainable systems for water management to cope with both theoretical and practical urban water challenges.

The conceptual framework presents sustainability drivers (environmental, social, and economy), which are threatened by pressures from ICTs, availability, and accessibility to clean and safe drinking water. Urban resilience such as reliant cities, improved accessibility, and innovative ICT maps up to the impacts of the sustainable human ecosystem. To meet the year 2030 sustainable development goals, human ecosystems such as agriculture (food), quality of life (human well-being), and economic growth (financial stability) must be improved.

Formulations of water paradigms have emerged, for example, sustainable urban water management, integrated water management, and smart and resilient cities. Additionally, other formulations are often regarded as trending in a series of urban water management. The proposed framework provides a comprehensive understanding of how pressures such as urbanization, water accessibility, and ICTs impact urban water management. This framework further addresses the urban sustainability of social living that is intertwined with socio-economic growth and environmental by citizens. Finally, the framework on the social aspect of urban living addresses cultural diversity, social equity to the accessibility of safe drinking water, and other urban resources.

5 Contribution

This paper presented a theoretical framework that provides guidelines for developing solutions that address urban water management. To address the aim of the study, research questions were formulated to support the primary aim. Research questions 1 and 2 were addressed through the SLR method.

The SLR addressed RQ 1: What factors influence social sustainable urban water management? factors that impact sustainability, namely, Water Accessibility, ICT, and household water management.

Further RQ 2: What theories are used to address socially sustainable urban water management? was addressed as one theory was retrieved from literature which was the basis of finding relevant theories under sustainability. The results of the SLR approach adopted in this paper discovered that out of 31 reviewed papers with only one article using a theory of social movement.

Finally, RQ 3: How can a framework be developed for sustainable urban water management societies? was addressed by proposing a conceptual framework with theoretical connections to the theory of socio-technical systems.

6 Recommendation

ICTs as a societal transformation enabler present good governance, based on reliable information gathered and shared through ICTs. ICTs present a potential for managing uncertainty and reducing unanticipated risks of urbanization and overconsumption of urban resources. This paper recommends the design, development, and implementation of a societal system. For example, an integrated urban water system that will present easy-to-use and understand urban water information to the citizens, which will also consider internal and external conditions such as urbanization. Unleashing the power of ICTs for enhancing citizens with relevant water knowledge and becoming wiser in terms of urban resource consumption (water and energy) is a recommended approach for realizing the 2030 government development goals.

Future work—the conceptual framework presented in the study is not tested, therefore, work can be undertaken to test the framework. The results from testing the framework can be used to develop guidelines that can be used to inform stakeholders on how to use ICTs, improve accessibility, and have resilient cities.

7 Conclusion

Water demand is included in the top five key risks globally over the years. In the twenty-first century, the sustainability of urban water management is a critical concern. Limits in governance, including institutional inactivity and disintegration, an absence of professional and organizational capacity, and failure to adopt new practices are SUWM challenges. ICT in Urban water management have only been used for performance cost-factor analysis. ICT used correctly present opportunities for developing countries for cost-effective ICT-integrated solutions that can improve sustainable urban societal growth.

A lack of theories to understand the phenomena(s) of urban water management was spotted. A socio-technical system has been adopted as a theory to build a framework that will lead to systems that are more acceptable to end-users (citizens) and deliver better value to stakeholders (water authorities). It is further noted that the theory socio-technical system was chosen to give emphasis to the mutual interrelationship between urban citizens and technologies and to reinforce the program of shaping both the technical and the social aspects, so that efficacy and civilization would not oppose each other. This framework is known to have an impact on agriculture, quality of life, and economic growth. The framework, therefore, addresses RQ 3: How can a framework be developed for sustainable urban water management societies?

The acceptance of ICT use by urban citizens (social community) to do water management has to be investigated. ICT has an opportunity to address real-time monitoring and public engagement. This will help address or rather test the aspects of the proposed framework for effectiveness.

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Leakage Detection and Automatic Billing in Water Distribution Systems Using Smart Sensors

Kofi Sarpong Adu-Manu, Charles Adjetey, and Nana Yaw Ofosu Apea

Abstract Reading household and industrial meters are essential activities performed by water companies in most developing countries. Meter readings involve the collection of water consumption units, diagnostics, and status data from the meter devices. In Ghana, meter reading officers go from house to house, institutions, organizations, and other consumers to record the water consumed every month. Two main challenges arise from manual water readings: (1) under-reading, which results in undercharging the customer, and (2) over-reading, which results in overcharging the customer. In each case, either the utility company or the customer is affected during the billing processes. This study adopted wireless sensor devices to automatically collect water readings and detect leakages in pipes. The sensors are configured with a set calibration factor to measure water flow readings accurately. We discovered that the sensors could detect leakages in the pipe by analyzing the readings obtained. Our results showed that an automatic water monitoring system accurately measures water consumption. We observed that 20 ml/sec and 30 ml/sec were recorded from the two sensors at low pressures. The volumes recorded were 500 ml/sec at high pressures, indicating that the volume of water increases at high pressures.

Keywords Water Leakage Detection · Smart Sensors · Water Distribution System · Smart Meter Billing · Wireless Sensor Networks · WSNs

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1 Introduction

Water makes up 71% of the world's surface area. Water is essential to all living things at large (Adu-Manu et al., 2017). Water is a valuable compound required for sustainable national development. Currently, only 2.5% of the world's water is available for human consumption. Water is helpful for industrial and domestic activities. For domestic, water is used for cooking, bathing, and washing, among others. For industrial, water may also be used for fabricating, washing, diluting other substances, and cooling heavy-duty equipment (Adu-Manu et al., 2017, 2020; Sensors, 2013). Water Distribution Companies (WDC) are responsible for channeling water to various households/companies for utilization. Consumers make payments to the WDC for the volumes of water they consume monthly. Water distribution system leakage is a severe problem that affects water companies and their customers worldwide. It is no wonder, then, that it has gained much attention from academics and practitioners in recent years (Ali & Saidi, 2021; Kumar et al., 2020; Puust et al., 2010; Arul Dharani Pathy et al., n.d.; Vrachimis et al., 2021).

Challenges bounding to the provisioning of quality service by WDC are leakages in pipelines that cause enormous amounts of water going waste, resulting in inaccuracies in the meter readings. Therefore, consumers receive the wrong water bills in such instances. They become dissatisfied with the services provided by the WDC. These challenges have remained an albatross around the neck of stakeholders of WDCs in most developing countries. Water leaks can lead to high rates of domestic and industrial water consumption. These leaks happen regularly, but they mostly go unnoticed by consumers. A sudden rise in a customer's water usage can cause imbalances in the distribution system's water pressures, forcing the department to invest money to satisfy a demand-driven by consumer losses (Sithole et al., 2016). There is, therefore, the need for WDCs to tighten their control over water management schemes (Lin et al., 2008).

Billing errors and excessive water use have contributed significantly to commercial water loss (Brindha et al., 2019). Unreliable water meter readings cause billing errors and, in some cases, a lack of staffing to obtain correct water usage figures, resulting in poor data handling. Dripping taps, running toilets, and pipe leaks are common causes of increased water consumption (Sithole et al., 2016). Meter reading officers in most developing countries such as Ghana visit homes, institutions, organizations, and other water users every month to record the amount of water consumed. Manual water readings present two significant challenges: (1) under-reading, which leads to undercharging the customer, and (2) over-reading, which leads to overcharging the customer. The traditional method can lead to irregular water meter monitoring and inefficient systems that warn the department in real-time if there are any water meter readings. Billing errors are caused by inconsistencies, resulting in the consumer paying an inflated bill or the department losing money due to the errors.

An intelligent water distribution system will consist of a real-time network with flow sensors and other devices that constantly track the system. Many different

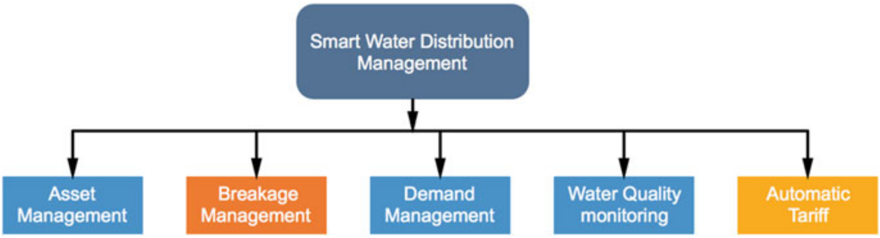


Fig. 1 Key components of a Smart Water System

parameters can be controlled, including pressure, flow rate, and temperature. The existing distribution system has a high rate of breakage. Locating and establishing illegal relations is time-consuming.

Figure 1 shows the critical components of a smart water system. Asset management comprises the pipelines buried underground to transport water from one location to another. The overall lifetime of these pipelines is also short, posing the risk of failure at some stage. As a result, current pipeline lifespans must be extended to avoid critical pipeline failure. Corrosion is a concern since the pipes are buried underground. When detecting breaks or leaks in breakage management, WDCs require more workforce to survey existing pipelines, which takes time. Using an intelligent water distribution system can reduce the time taken to detect the possible region of breaks, which aims to minimize the effect on customers. The water supply companies can determine which regions have the highest water demand in demand management. When there is no need for water, simply rising the pressure causes pipes to burst to create unnecessary leakages. Water quality monitoring (WQM) is essential to reduce the effect on customers' health. A smart sensor array could be installed to provide real-time water monitoring in the network. It is possible to consider water quality parameters such as pH and turbidity.

In automatic tariff, the water distribution company will set up an automated monthly tariff generation system for customers through a smart water distribution system. Additionally, customers will be able to easily manage their water usage and make payments. Hence, in this paper, the authors sought to provide a cutting-edge solution using an automatic water monitoring system as an alternative to record the volumes of water running through pipes and forward the data to WDCs for billing. A device that can monitor possible leaks and report current household water consumption levels in real-time could lower consumption rates and early detection of leaks such as dripping taps and pipe leaks (Sithole et al., 2016). This paper's system defined and developed addresses incorrect meter readings caused by human error. Despite this, the paper tackles the late detection of water leaks in pipes using an automated system to detect leaks in pipes for efficient billing. The smart sensor-based water distribution system will also make it easier for the department to keep track of precise water usage levels and assess the reliability of the water delivery system. Therefore, it is not difficult to design; it is appropriate for private homes. The sensor devices are small and simple to attach to home pipes to detect leaks in pipes.

When implemented in homes, consumers will benefit because it will alert them to leaks, allowing them to avoid overpaying utility bills. Water distribution companies can also rely on the system to send accurate and timely bills to consumers. However, most importantly, it will help protect the world's most valuable resource.

The proposed WSN system prototype's ultimate goal is to automate leakage detection systems to help the water distribution company's long-term use and control its water resources. The use of WSNs for monitoring water distribution pipes will support the sustainable utilization of the water resources. The relevance of this project is to demonstrate that sensor nodes are energy efficient and, therefore, when employed in water distribution systems, it would be sustainable due to its low cost.

2 Related Works

Water is essential to life on earth; hence, focusing on its production, management, and reporting is equally important. Water pipes are susceptible to leakage, reducing the quantity of water. Secondary contamination of water bodies and water quality risks is likely due to leakage (Hu et al., 2021). A variety of factors can contribute to leakage in distribution systems. Poor pipe connections, internal or external pipe corrosion, and mechanical damage caused by excessive pipe load are just a few examples (e.g., by traffic on the road above or by a third party working in the system). Ground movement, high system pressure, excavation damage, pipe age, winter temperatures, pipe defects, ground conditions, and shoddy work are all common factors that contribute to leaks. As a result, leaks can cause infrastructure and third-party damage, including water and financial losses, energy losses, and health risks. In this section, we briefly describe water distribution and sensor networks and some existing works in other areas (Puust et al., 2010).

2.1 Water Distribution and Wireless Sensor Networks (WDWSNS)

Water needs are not being met globally in developed and developing countries, where climate change and economic water shortages are the most pressing issues. Many areas of the earth cannot produce enough fresh water for the inhabitants. Despite the limited amount of freshwater sources, water companies cannot create or sustain water distribution networks that satisfy the demand due to economic scarcity (Kumar Sarangi, 2020; Maroli et al., 2021; Arul Dharani Pathy et al., n.d.). In Adu-Manu et al. (2017), the authors classified leakage detection systems into internal and external detection techniques. The classification was based on the technical nature of the leakage detection performed. Due to the limitations of these

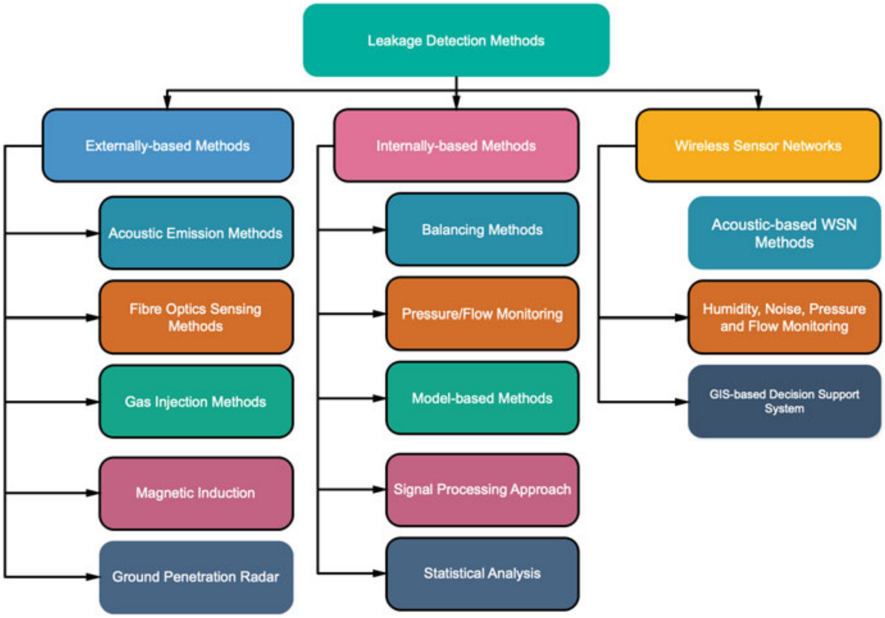


Fig. 2 Leakage Detection Approaches—Classification

detection methods, there is a need to introduce new ways of detecting leakages both internal and externally. The new approaches should be cheap (that is, low cost of installation), reliable, capable of deploying thousands in the field, able to operate in harsh environments and report leakages in real-time. The introduction of Wireless Sensor Networks (WSNs) in water distribution systems is one such approach (see Fig. 2).

Traditionally, leaks are typically detected in pipes with acoustic equipment that detects the sound or vibration caused by water when it escapes from pipes under pressure. Listening instruments such as listening rods, aqua phones (or sonoscopes), and geophones are examples of acoustic equipment (or ground microphones). Acoustic equipment is used to listen for leaks at pipe-to-pipe communication points like fire hydrants and valves (Lin et al., 2008). Locating the leakage point is time-consuming and repetitive when using traditional techniques. As a result, a more effective water monitoring system is needed to efficiently minimize water leakages. The traditional leakage-monitoring systems developed to address this challenge are not sustainable (Yazdekhasti et al., 2020). Hence, wireless sensor network (WSN) devices have proven to be a better replacement in water distribution systems in the local area to control water flow, pressure, and vibration at various locations.

Sensor nodes can also identify “hotspots” or areas of the distribution network that are more vulnerable to structural failure ahead of time. These capabilities are critical for reducing the time it takes to detect and repair failures and mitigate the effects on water supply (Lin et al., 2008; Whittle et al., 2013). A typical water distribution

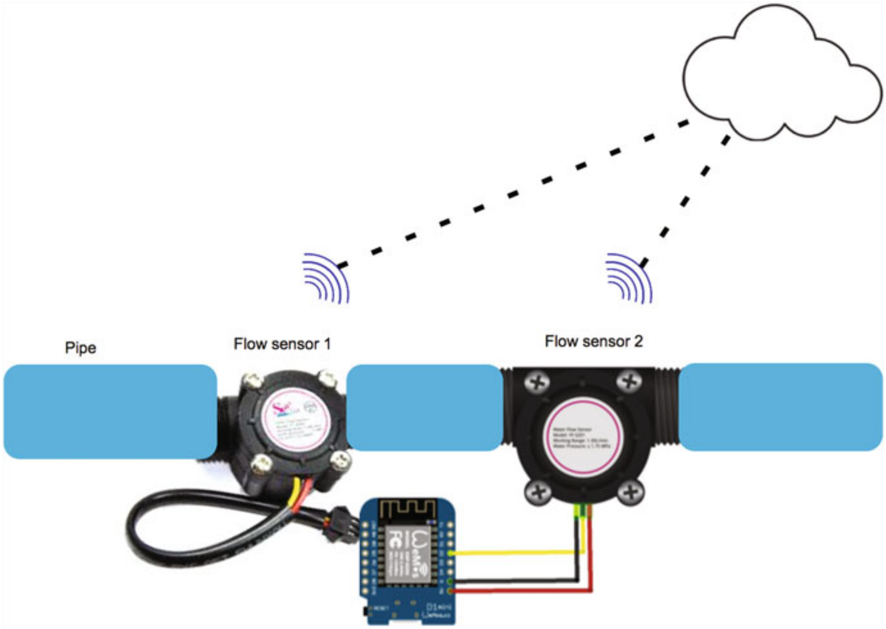


Fig. 3 Water Distribution System

system is illustrated in Fig. 3. Flow sensor one (1) and sensor two (2) collect water flow data and transmit the data via the wireless channel to the cloud. In the event that there are leakages, alerts will be triggered. Wireless Sensor Nodes can detect and locate pipe failures as soon as they happen.

WSNs have several advantages: easily deployable, flexible, inexpensive, scalable, self-organized, and distributed (Engmann et al., 2020). WSNs can provide water companies with real-time data on leakages in pipelines for effective decision-making, and they will also provide consumers with accurate billing. Sensor networks are beneficial when deployed because they can detect leakages, reduce water losses, and improve water distribution networks (Christodoulou et al., 2010).

2.2 *Existing Leakage Detection Systems*

Several attempts are proposed in the literature to determine efficient ways to report water consumption using smart meters. Previous work by Cominola et al. (2015) focused on water pipeline monitoring and leakage detection by introducing intrusive and non-intrusive metering. Their work ensured direct estimates of residential water use and the total water flow at the household level. The authors employed accelerometers, ultrasonic sensors, pressure sensors, and flow meters to undertake this experiment successfully (Cominola et al., 2015).

In the work done by Ali and Saidi (2021), the authors designed a system that automatically could extract individual water flow consumption readings and upload the data to the cloud for analysis and visualization. Their system alerts homeowners of any inappropriate water use based on the data analysis. They employed Raspberry Pi 4, which served as the system's brain, with the Pi camera serving as the image capture mechanism and the YF-S201 water flow sensor serving as the water flow reader. Their system was able to detect any water leakage reliably and warn the residential owner. Farah and Shahrour in 2017 proposed a technique that employs Smart Water technology to detect water leakage. They combined the traditional water balance method with the minimum night flow approach to design their system. Their approach has been used in a large-scale pilot project at the University of Lille's Scientific Campus. Their study observed that a leak warning is triggered if the night flow sensor reaches the thresholds. Their data analysis technique allows for the rapid detection of pipe bursts, minimizing leakage time. Their method allowed identifying 25 previously unreported leaks, resulting in a 36% reduction in Non-Revenue Water (Farah & Shahrour, 2017).

Other researchers have designed in-home consumption displays (IHDs) and consumption feedback systems to encourage consumers to reduce their water usage. Users received an email for the amount of water consumed and information on leakages detected. The in-home consumption displays (IHDs) laid on the underlying principles of smart meters to provide real-time information (Cominola et al., 2015). The authors narrowed their scope to industrial and proposed systems to monitor and control liquid flow in industrial pipelines in other projects. Electrovalves and flow meters were connected to the pipes to read pulses (a liter per every 5600 pulses) from the flow sensors (Anto, 2014). In Whittle et al. (2013), the authors designed a platform known as the WaterWiSe for managing and analyzing data from a network of intelligent wireless sensor nodes to track hydraulic, acoustic, and water quality parameters in real-time. WaterWiSe performs dynamic prediction of water demand and hydraulic condition, online detection of events such as pipe bursts, and data mining for longer-term trend recognition. The project was implemented in Singapore.

In Christodoulou et al. (2010), the authors proposed two main approaches to overcome the water losses associated with the underground water distribution system to improve revenue losses in Cyprus. The projects WaterSense and Urban Water Distribution modeling, simulation and optimization of leakage detection via sensing technologies were aimed at an integrated management approach that combined analytic and neuro-fuzzy decision support system, GIS and WSNs. Real-time data acquired through these projects were transmitted from a distributed ad-hoc wireless sensor network to the Cyprus Research Centre. Parameters measured included flow, pressure, and moisture. WaterSense was powered by solar and batteries. The authors (Lin et al., 2008) proposed a specific use case for wireless sensor networks, dubbed the monitoring of water delivery networks. They defined a channel measurement method for determining an effective path-loss model and a potential communication model for the water distribution monitoring network. The flat earth two-ray model was used to validate the precision of their measurement method (Lin et al., 2008).

In Kumar et al. (2020), the authors designed a water distribution and leakage detection system. Their leakage detection system is based on programmable logic controller (PLC) and supervisory control and data acquisition (SCADA) software. The system is designed to distribute water according to demand based on the number of people living in a particular area. The PLC-based automated system with an embedded controller has already been pre-programmed to perform the tasks, and the results are displayed in a ladder diagram using Picosoft software. Each area has its threshold, and the water is dispersed from the main storage tank to the following tanks. Flow sensors are used to measure the amount of water provided, and solenoid valves are used to open and close valves automatically.

Other researchers extended their work from detecting leakages in pipes to stopping the water flow (Alam et al., 2016; Brindha et al., 2019; Gavande et al., 2020). Most of these researchers used a microcontroller to continually read the data from multiple flow rate sensors, thereby continuously monitoring the water flow and signaling the solenoid valve to stop the water flow if the data recorded from the sensors is greater than the set threshold. In another work, the researchers introduced the cloud logging technique to enable others to gather data and perform analysis simultaneously (Suriya, 2017). One research work that adopted a smart meter explained that the pulses generated go through recording and are time-stamped by a data logger. The data collection may involve: (1) an older style data logger, where data stays in the box until a technician comes and downloads it; and (2) modern systems in which information is relayed directly to the web, or a central server using wireless modems, dial-up links, and secure connections via a company's LAN, to send the signal via electrical wires (Hauber-Davidson & Idris, 2006).

3 Leakage Detection Approach

The water leak detection system can be installed in existing pipes by simply attaching the flow rate sensors in the water flow path. The sensor node does not block water flow; instead, it collects data on flow rate and transmits it to the appropriate location. The authors applied the concept of serial programming, where the fundamental function of the monitoring system was built around the application using the water flow sensors. A flow sensor is a system that detects fluid flow rates. A flow sensor is a sensing element used in a flow meter or flow logger to record fluid flow. The amount of water entering each tank is measured by a flow sensor in this device. A complete embedded system has been designed to carry out the monitoring processes expected to efficiently manage leakage reporting and billing.

3.1 Flow Sensor

The flow sensor shown in Fig. 4 consists of a plastic valve body, a rotor, and a Hall Effect sensor. Anytime liquid passes through the valve, the pinwheel rotor rotates, and its speed becomes directly proportional to the flow rate. When the pinwheel motor revolves, the Hall Effect sensor generates electrical pulses, which are converted into electronic data. When an external magnetic field is applied at right angles to an electric current flowing through a conducting material, an electric potential is produced perpendicular to both the current and the external magnetic field. The flow rate is directly measured using this principle.

3.2 Hardware Configuration

We configured the hardware by connecting the flow sensors and the pipe. The sensors are configured with thin wires and glued inside a polymerizing vinyl chloride (PVC) pipe. The sensors triggered when water flowed into the pipes. The wire has a 5 V of power passing through it, and it connects the Arduino microcontroller and a breadboard. The 5 V power is needed simply because a higher voltage may cause damage to the Arduino board. The first sensor (i.e., sensor 1) transmits data to pin D2, and the second sensor (i.e., sensor 2) sends the data to pin D3, as shown in Fig. 5. Water flow readings are collected every 10 seconds. The values are stored in a web server for decision-makers to use, management and planning.

3.3 Communication Infrastructure

Another aspect of sensor network design that requires careful consideration is selecting a suitable communication medium and appropriate communication protocols (Engmann et al., 2021). Current device operators have chosen a GSM/GPRS approach, despite the industry's preference for GSM/SMS (Ediriweera & Marshall,

Fig. 4 Water flow rate sensor

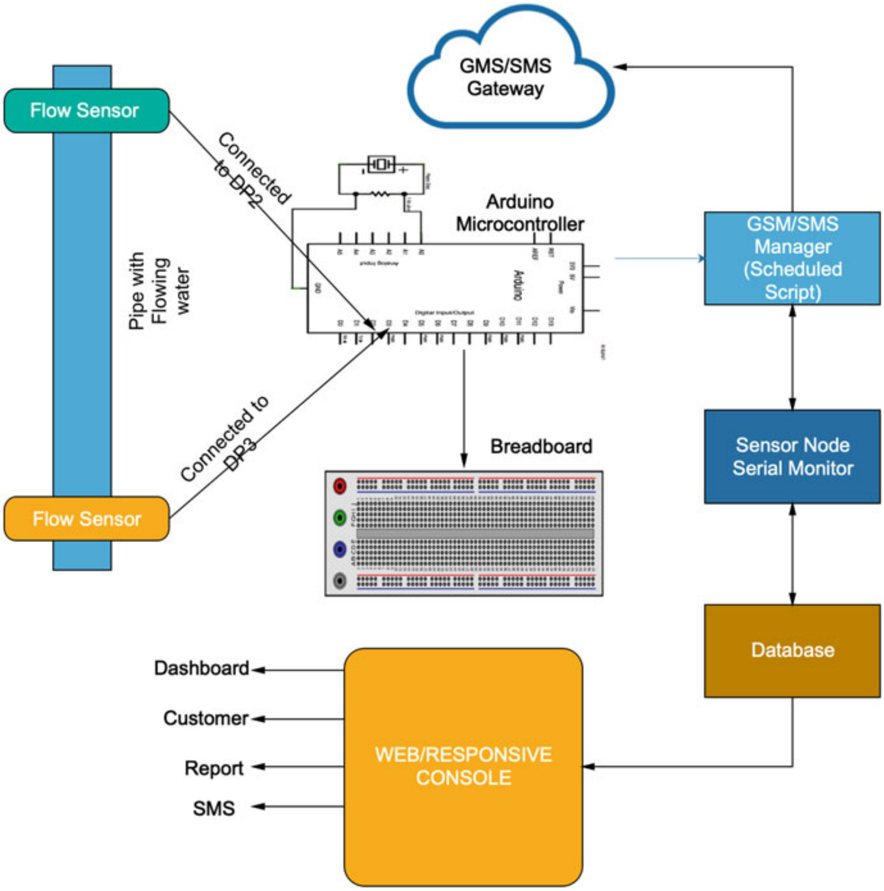


Fig. 5 Leakage Detection Infrastructure

2010). Figure 5 depicts the coordination between the system's different components. The sensors are connected to an Arduino and breadboard and the machine node. The data is collected through a gateway station into a database and uploaded on a web portal in real-time. The data obtained are made available to the public on a web page through a GSM/SMS gateway. An SMS is sent to users via the SMS gateway to provide them with the most up-to-date information on billing and payment information.

3.4 Automatic Billing System

In WDS, if leaked pipes are not detected on time, water may be wasted, affecting billing in most cases. Our system employs Automated Meter Reading (AMR). AMR

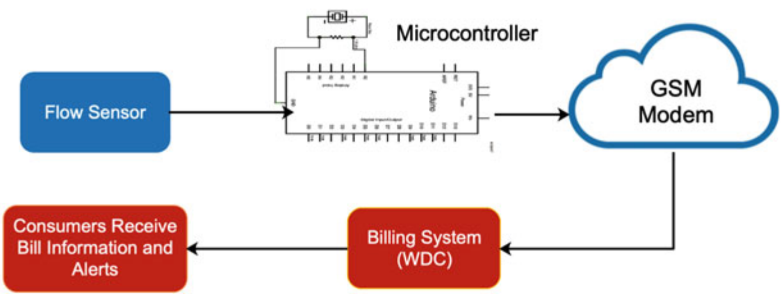


Fig. 6 WDCs Billing Infrastructure

uses advanced network technologies such as Wi-Fi, GSM modems, and power line communication to collect consumption, diagnostic, and status data from water meters or energy metering devices. The data is then transferred to a central database for billing.

Flow measurements are recorded and saved in a database for billing and analysis. Consumers receive bills and leakage alerts based on their consumption, as shown in Fig. 6. The billing and leakage reports are delivered to system users, as shown in Fig. 7. The microcontroller receives the flow sensor's input. The value is then sent via SMS to the bill calculating unit using a GSM modem. Another GSM modem received the value and delivered it to a system for bill calculation using bill calculating software. The bill amount is then sent to the customer via SMS. The customer can then pay their bill online.

4 Implementation and Architectural Design

For a leak to be detected by water distribution companies, enough water would have been wasted. Broken seals, clogged lines, corrosion, damaged pipe joints, intruding tree roots, and other factors give rise to leakages in pipes which causes water loss.

Figure 8 shows a schematic diagram illustrating the components and their interaction. The major components include the Arduino microcontroller, the flow sensors, the breadboard, and a smartphone.

The deviation value is the standard of measurement to determine whether more than enough water has gone wasted or not. The utility company determines the deviation value (see Algorithm 1). Once the difference in initial and final flow rate exceeds the set deviation value, there is possible leakage occurring in some part of the pipe. The algorithm below depicts the leakage detection process. A detailed flowchart showing the overall process is illustrated in Fig. 9. Figures 10 and 11 represent the setup for the experiment where the sensors are connected to the Arduino board. Figures 10 and 11 show a simple view of the system hardware and software design and their underlying components. The PC supplies the Arduino

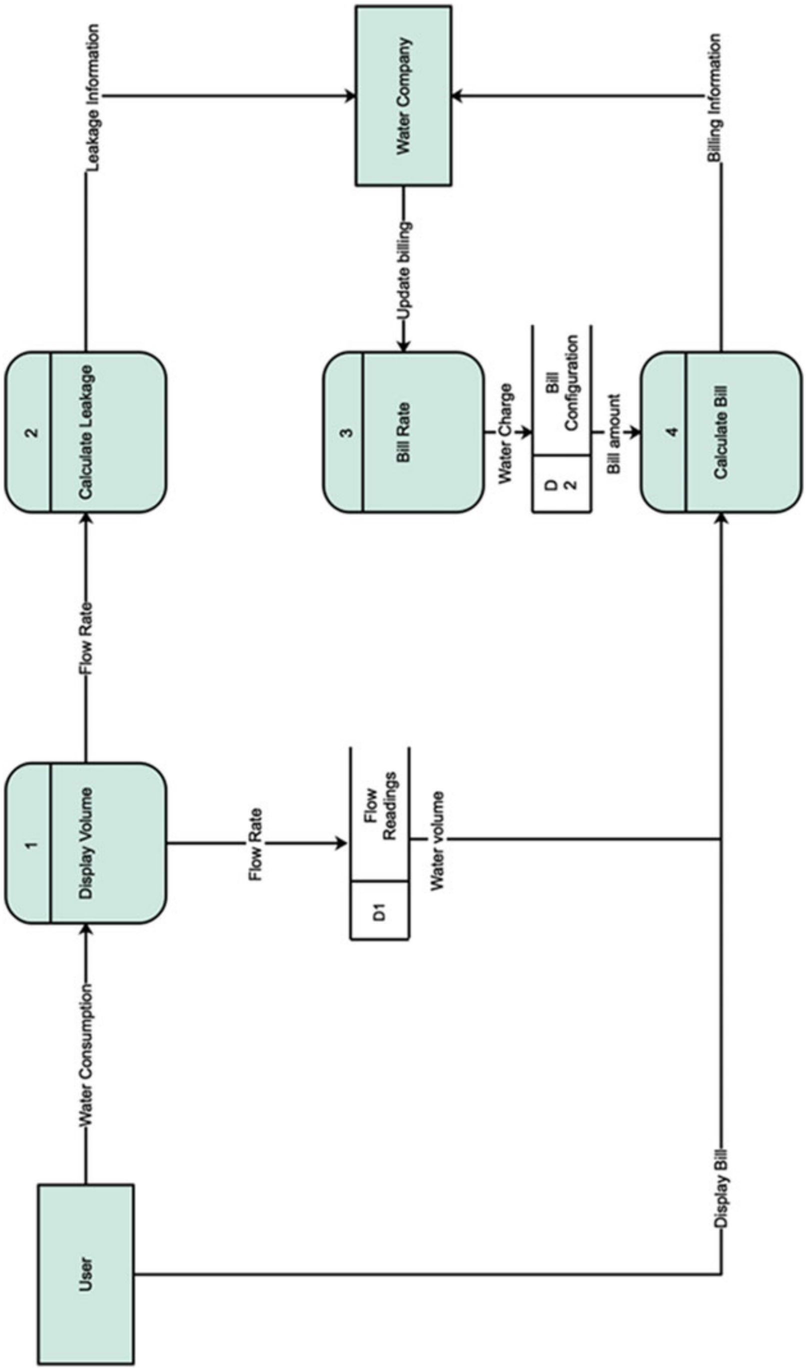


Fig. 7 Flow Diagram for Billing System

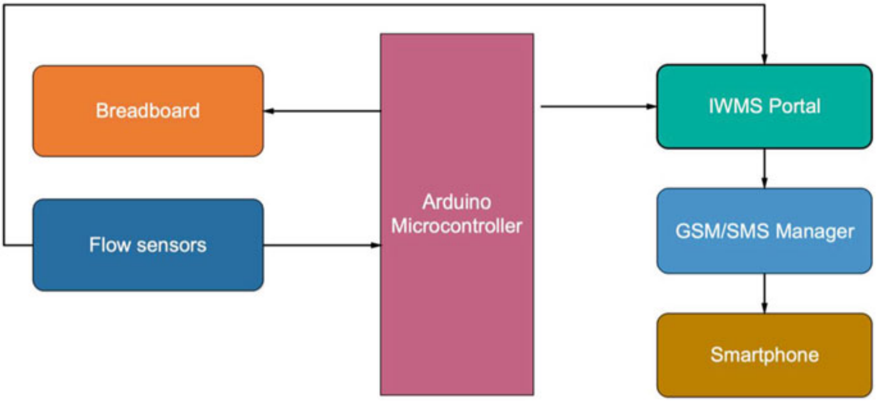
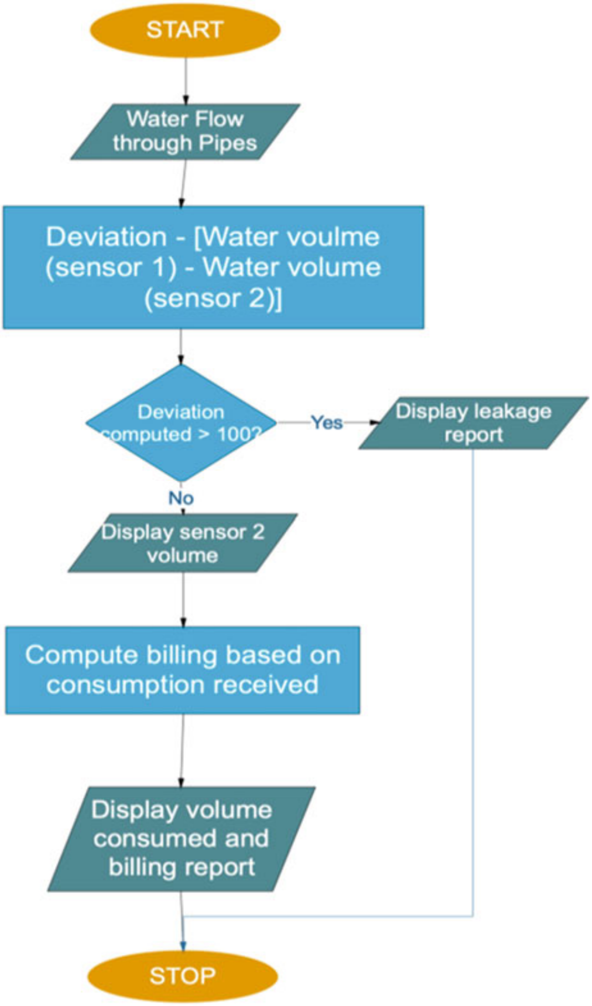


Fig. 8 Schematic diagram

Fig. 9 Flowchart illustrating leakage detection



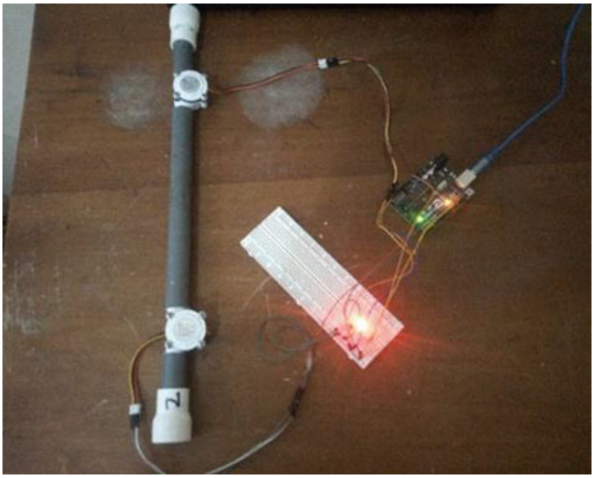


Fig. 10 Pipe connected to Arduino

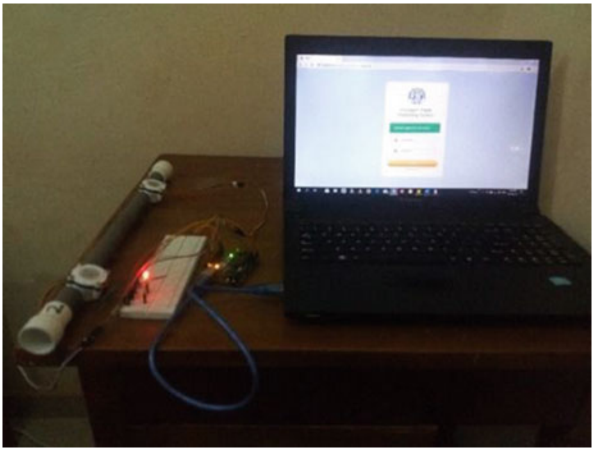


Fig. 11 Prototype setup

board with a power of 5 V. The LED displaying a red light verifies that all parts are working correctly.

As shown in Fig. 12, the system dashboard receives and displays all the information regarding leakages detected, water consumption, and billing information. Users require relevant credentials to log in to the web portal to access the information. The dashboard also displays information on the sensor calibration, the number of connected devices, the aggregate flows, and the deviation. The flow readings are displayed to check the volume of water that both sensors have recorded. We performed two major tests: (1) low-pressure flow and (2) high-pressure flow. Figure 13 shows a low water pressure test. The water can flow through the pipe for a time frame (i.e., about 30 to 60 seconds). The flow is observed through the pipes. Readings occurring at each sensor is recorded. In Fig. 14, the researchers

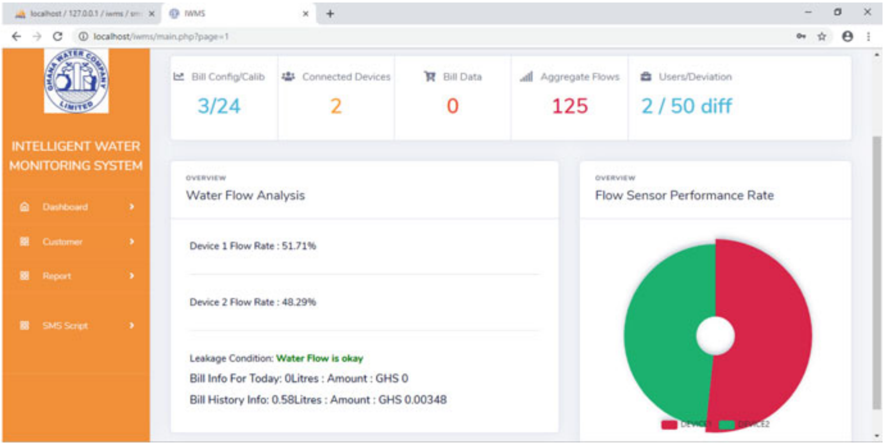


Fig. 12 System Dashboard

Fig. 13 Low-pressure test

allowed water to flow through the pipes with high pressure for 30 to 60 seconds. The values read by the two sensors are recorded for different pressure volumes.

5 Results and Discussions

We conducted tests to determine the effect of low and high water flow pressures, and we discussed some impressive test results. Water flows slowly through the pipe during the low-pressure test. Figures 15 and 16 depict a graph of water volume versus flow rate. We discovered that the first sensor had a maximum reading of 37 ml, and the second sensor had a maximum of 35 ml. Water flows very quickly through the pipes at an increased flow rate during the high-pressure test. The first

Fig. 14 High-Pressure Test

Fig. 15 Flow rate measured from sensor device 1

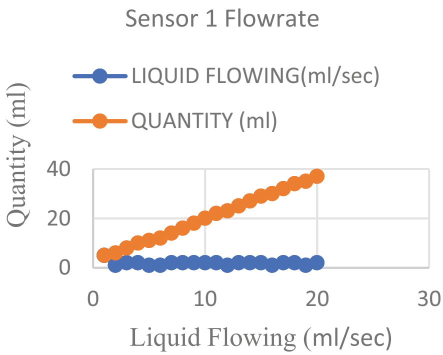
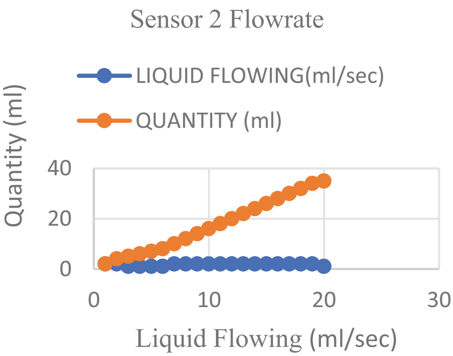


Fig. 16 Flow rate measured from sensor device 2



sensor device recorded maximum readings of 462 ml, while the second sensor device recorded readings of 506 ml (see Figs. 17 and 18). In Figs. 18 and 19, the water flow rate through the pipes was measured for low-pressure and high-pressure

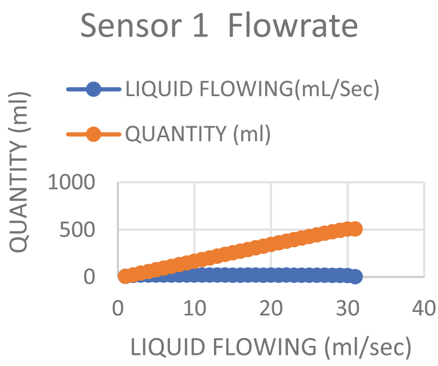


Fig. 17 Water volume obtained from sensor device 1

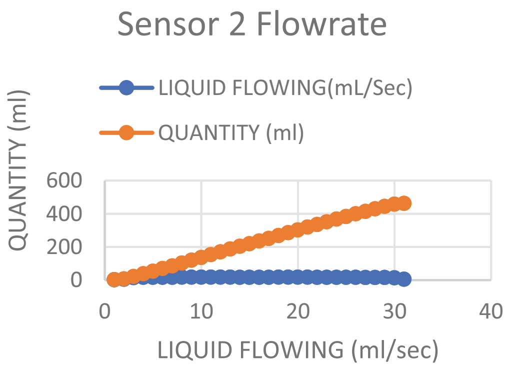


Fig. 18 Water volume obtained from sensor device 2

scenarios. In Fig. 18, the volume of water measured about 40 gpm at 40 ml/seconds. In Fig. 19, the volume of water measured about 450 gpm at 63 ml/seconds (Fig. 20).

6 Conclusion

Serial programming, particularly on sensor devices, has many applications. Because of the enormous demand for water as a resource, one of the key areas is water monitoring. It is necessary to guarantee that water is preserved and does not leak out. It's also worth noting that customers are entitled to a bill that accurately reflects the volume of water consumed over time. As a result, the research project has implemented a water volume monitoring system. It calculates usage depending on the exact amount of water delivered to the customers. The goal of automatic water consumption monitoring is to eliminate the need for meter officers to collect and submit water usage data. When billing and leakage issues emerge, the system can properly alert consumers. More sophisticated sensors may be used to record large volumes of water in the future.

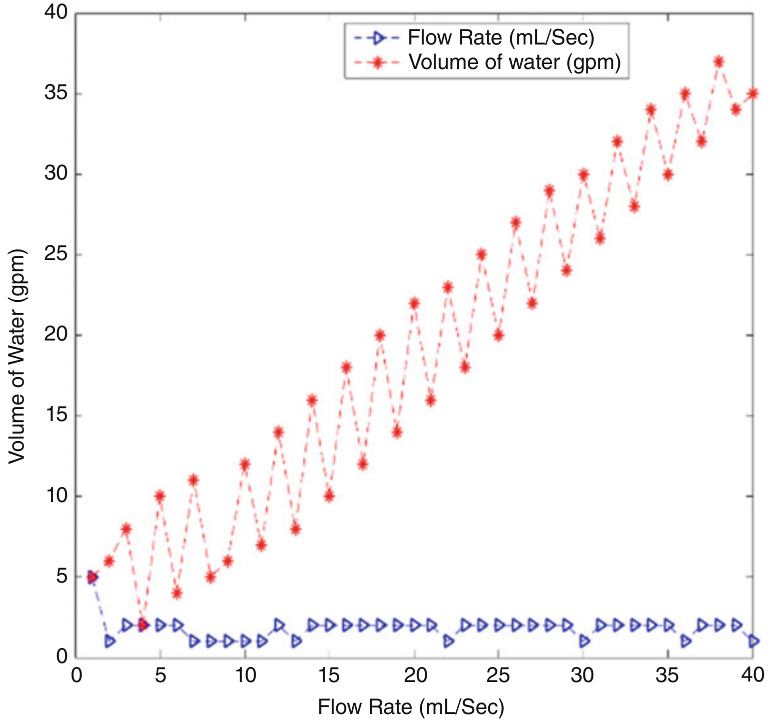


Fig. 19 Low water pressure test

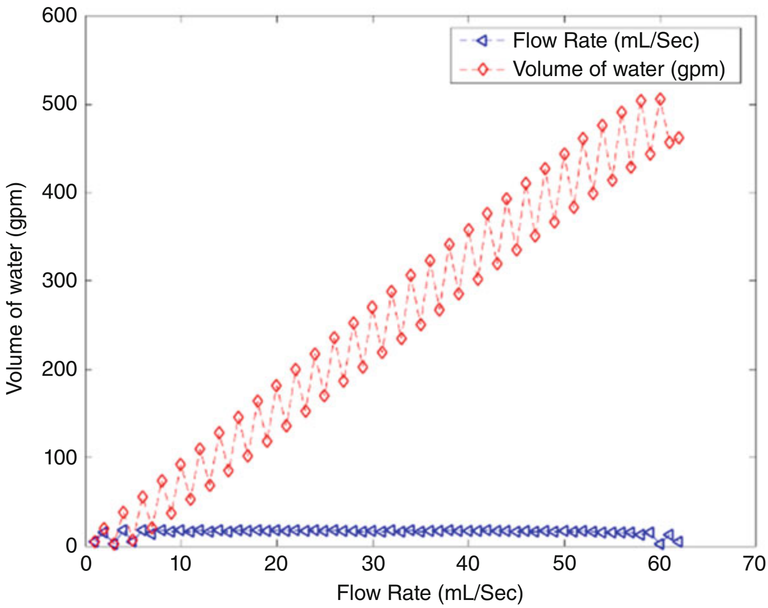


Fig. 20 High water pressure test

Declaration The authors declare that this is an original work conducted by the authors.

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E-Government Initiatives toward Smart City Development in Developing Countries

Rebecca Njuguna and **Sarah Dsane-Nsor**

Abstract Societies are progressing rapidly toward socio-technical systems where the physical and virtual are more integrated. This is in a bid to address environmental and socio-economic sustainability. Smart technologies have been identified as part of critical infrastructure supporting sustainable development. Developing countries have a crucial role to play in sustainability, with the projections indicating that cities in Africa and Asia will host larger populations in future than current developed cities. Given the problems that have plagued developing countries in the past, it is important to understand their preparedness for the responsibilities of the future. This study therefore conducted a systematic review with the objective of identifying smart initiatives implemented by governments in developing countries in collaboration with other stakeholders. 25 papers were reviewed, and 9 initiatives discussed. The review reveals a variety of initiatives spanning across energy, water, transport, and e-participation. A scarcity of empirical studies reporting on implemented initiatives was noted, particularly from Sub-Saharan Africa from which only South Africa was represented.

Keywords Smart cities · Smart governance · Digital transformation · E-government · Developing countries

1 Introduction

Over the last fifty years, developing countries have experienced rapid urbanization as more people move to the cities. Approximately 55% of the world's population lives in urban areas and that percentage is projected to rise to 68% by 2050 (Kolesnichenko et al., 2021). Rural–urban migration is comparatively high in developing countries than in developed countries (Kojima, 1996), as more people move to the cities for jobs due to industrialization. As a result, most resources such as

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utilities are consumed in cities, which contributes to increased economic value but also results in environmental issues such as pollution and poor waste management. For instance, over 50% of energy worldwide is consumed in cities, contributing to high carbon dioxide emissions (UN-Habitat, 2008). The adverse effect of industrialization has thus led to the global quest for change to create more eco-friendly and sustainable communities. This sustainability mission coupled with the drive to improve people's standards of living has led to initiatives such as "smart cities."

Smart city is an expansive domain. It encompasses management of natural resources (Smart Environment), physical infrastructure such as transport and communication (Smart Mobility), open and transparent decision-making (Smart Governance), collaborative ecosystems and increased competitiveness (Smart Economy), improved social and human capital (Smart People) and improved well-being of citizens (Smart Living) (Lima, 2020). There are varying definitions of "smart cities", most of which simply relate smart cities with the accumulation of big data and use of Internet of Things (IoTs) (Kolesnichenko et al., 2021). The term "smart" does not simply mean that each smart city initiative is embedded with advanced technology. Rather, it points to how each aspect of a city or community can be integrated, using human-centered design and digital technologies (Korachi & Bounabat, 2019). "A smart and sustainable city can be conceived of as an urban entity which is able to integrate available social and digital technologies and to coordinate extant knowledge with the purpose of tackling the environmental, social, and economic issues that affect its long-term viability" (Palumbo et al., 2021, p. 2). This definition is more expansive and captures the essence of smart cities: improving the lives of citizens (Lima, 2020).

Smart governance as outlined by Lima (2020) is a sub-domain of smart cities whose concern is creating new forms of collaboration enabled by information and communication technologies (ICTs) for more transparent processes and better outcomes (Jiang, 2021). The aim is an improvement of urban management underpinned by data-informed decision-making and the active participation of all stakeholders (Ranchod, 2020). Although used interchangeably sometimes, smart governance and e-governance have some distinctions. E-governance refers to the adoption and use of ICTs in the public sector to improve service delivery and improve interactions between the government and citizens (Glybovets & Mohammad, 2017). E-government thus has a broader mandate of improving citizen engagement, service quality, efficiency, transparency, and trust (Lindgren et al., 2019). Smart governance narrows down to the processes and ICTs that enable the collection and seamless dissemination of data across various government institutions, translating into better quality services to citizens (Glybovets & Mohammad, 2017). The design, implementation, and evaluation of e-governance and smart governance initiatives vary with context.

The perspective of the developing context around smart city initiatives is underexplored. Developing context in this study refers to countries with a low socio-economic living standard, less developed industrial base, and a low Human Development Index (HDI) relative to other countries (Neverov, 2020). Therefore, this study sets out to conduct a systematic literature review to highlight e-government and smart government initiatives implemented in developing contexts. We also discuss an e-government initiative involving digitization of an asset register by a Provincial Government Department in South Africa. The review will be guided by the following research questions:

> What e-government initiatives have been implemented in developing countries and their objectives?

In the following section, we present a brief background of smart cities in developing countries followed by the methodology that has been followed to conduct a systematic search of literature. Thereafter a brief background to the topic is presented as well as the digital asset register project. The next section discusses various initiatives implemented in developing countries. Finally, concluding remarks and limitations to this review are presented.

2 Background and Related Work

Smart societies have risen from societies' progression toward socio-technical ecosystems where physical and virtual dimensions are integrated (Manda & Backhouse, 2018). Developing countries have a huge role to play in smart cities and sustainability.

Figure 1 shows the growth in urban population in developing economies over a ten-year period relative to developed economies. Continents such as Africa and Asia are projected to host the largest cities in future due to faster urbanization in the coming years than in currently developed continents (Heckman et al., 2016). It is

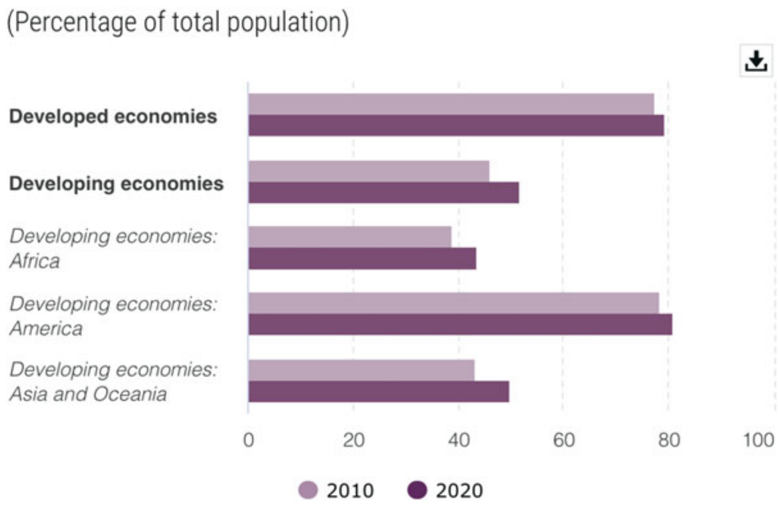

Fig. 1 Urban population by group of economies (UNCTAD, 2021)

thus important to understand the smart city developments in these contexts as a sign of preparedness for the future. Currently, cities in developing countries are already faced with a myriad of challenges such as poor waste management, poor water and electricity distribution, poor crisis management systems (Fashoro et al., 2021). These challenges cannot be solved by simply implementing ICTs. Rather, they require holistic, socio-technical solutions. Smart cities offer such a holistic approach to city transformation that integrates the people, technical infrastructure, and policy components.

For instance, the rapid urbanization requires concurrent expansion of infrastructure to accommodate the increasing population density in urban areas. Some cities are having to build higher buildings than they have previously, thus engaging with new architectural designs as well as challenges. Smart technologies are assisting in the design of complex structures by enabling faster construction, flexible architecture with open spaces, and disaster preparedness such as earthquake resistance (Quezada et al., 2021). In India, IoT devices have being used for surveillance to promote safety in cities (van der Hoogen et al., 2021). Other ways smart technologies have been used in developing countries include using global geo-ICTs data to identify and estimate populations lacking electricity coverage (Aina, 2017); and streamlining vehicle registration processes (Das et al., 2020). Some fundamental constraints in smart city implementations include skills gap (Fashoro et al., 2021), and difficulty to understand smart city concepts and how to implement them in smart city solutions (Anindra et al., 2018).

In 2019, the Hub for Education on ICT for Sustainability (HEdIS) project held a summer school themed “Digital Transformation for Sustainability in Smart Cities” (Osorio, 2019). The summer school activities included visiting various organizations that had implemented smart initiatives recently. One of the cases understudied was a department in the Eastern Cape Provincial Government. The department was struggling to account for all their assets to the auditor general due to the inefficiency of managing their assets manually. The department contracted a software development company to address the problem. The goal of the initiative was to help the department to get a complete and accurate digital register of their assets. The key stakeholders in the project were the provincial department and the auditor general. Besides developing a cloud-based system and translating the manual records into digital format, sensors were also installed on key assets such as vehicles for real-time monitoring and analytics. This initiative enabled the provincial department to not only become compliant, but to also benefit from clean data for better decision-making. Their employees also attained skills needed to unlock value through other smart initiatives.

The authors were both part of the 2019 HEdIS Summer School. They documented the provincial department’s initiative and developed an interest to understand what other smart initiatives have been implemented in developing countries, which led to this systematic review. This study explores the various e-government initiatives toward smart city development in developing countries. The next section outlines the systematic review process that was followed and the outcome.

3 Systematic Literature Review Methodology

This systematic literature review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analyses) protocol. Literature search started in late May 2021. The first step was to identify the keywords that would shape the scope of the study. Several phrases and combinations were applied iteratively until a set was found that produced the highest range of articles meeting the study aims. Smart cities and e-government are broad, transdisciplinary subjects. Focus was placed on the "smart" concept. Digital transformation appeared alongside e-government and smart government titles and was included in the final search strings. The following two search strings were used:

("e-gov*" AND "digital transformation" AND "smart cit*")
("smart gov*" AND "digital transformation" AND "smart cit*")

Four online databases were used to obtain the literature: Web of Science, Scopus, JSTOR, and EBSCOhost. Web of Science and Scopus were the most fruitful. This is because the two databases index sources from the world's leading publishers of smart cities research such as IEEE (Institute of Electrical and Electronics Engineers) and ACM (Association for Computing Machinery) (Pacheco Rocha et al., 2022). A filter to only return peer-reviewed articles was applied. Table 1 and Fig. 1 describe the screening parameters applied at the title, abstract, and full-text level, and the results of that process.

A summary of the process is presented in Fig. 2.

4 Findings and Discussion

Table 2 presents descriptive characteristics of the literature reviewed.

Of the 25 papers reviewed, 11 were journal papers, 10 were conference papers, and 4 were book chapters. Only 9 were empirical studies, while the rest were conceptual (7) and various types of reviews (8). The year of publication ranged from 2017 to 2021, corresponding with the increased interest in smart cities in recent years. Although the inclusion criteria attempted to maximize getting literature that

Table 1 Inclusion/exclusion criteria

Level	Criterion	Detailed criterion
Title	Keywords	Titles that did not have at least one of the keywords "smart governance," "e-governance," "digital transformation," or a "smart" aspect were eliminated.
Abstract	Smart initiative	Articles that did not mention a smart initiative within government or public sector were eliminated
Full text	Developing country context	Studies that did not discuss smart initiatives in developing countries were eliminated

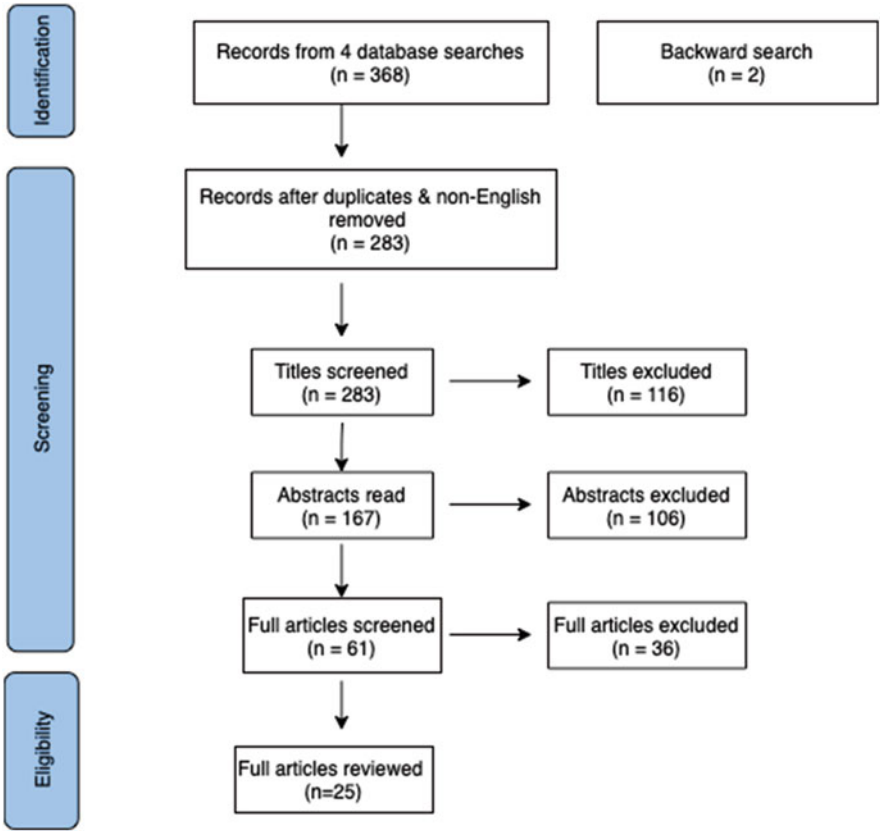

Fig. 2 Systematic review PRISMA flow diagram

discussed existing initiatives, only 8 papers contained initiatives. The rest had general discussions on smart cities or various types of frameworks and policies for smart city implementation. Backward searches did not yield more initiatives. This possibly points to a scarcity of reporting on smart city initiatives in developing countries. The ratio of empirical versus conceptual and review papers further supports that hunch as this review found more papers discussing various issues around smart cities theoretically than those who engaged empirically with a smart city component.

The following section discusses the initiatives found and their objectives.

(i) **Makkah Smart City** (Aina, 2017).

The project was designed to provide better support to pilgrims. It was funded through a public–private partnership with the Royal Commission Yanbu as the owner and regulator. Other stakeholders were telecommunication and network companies such as Mobily, Bayanat, Huawei, and Orange Business services. The

Table 2 Demographic characteristics of reviewed papers

Paper number	Type of publication	Context/Author affiliation	Type of paper	Initiative	Year
1	Conference paper	Russia	Empirical	⍰	2020
2	Journal article	Ecuador	Empirical	✓	2020
3	Journal article	Italy, UK	Review	⍰	2021
4	Journal article	Netherlands	Conceptual	⍰	2021
5	Conference paper	South Africa	Case study	⍰	2018
6	Journal article	Saudi Arabia	Empirical	✓	2017
7	Journal article	South Africa	Conceptual	⍰	2020
8	Conference paper	Indonesia	Review	⍰	2020
9	Journal article	Spain, Chile	Review	⍰	2020
10	Conference paper	Morocco	Conceptual	⍰	2019
11	Conference paper	Indonesia	Conceptual	✓	2018
12	Conference paper	Portugal	Conceptual	✓	2018
13	Journal article	Jordan	Empirical	⍰	2018
14	Journal article	Brazil	Review	⍰	2021
15	Book chapter	Brazil	Bibliographic review	⍰	2019
16	Journal article	Spain	Review	⍰	2020
17	Conference paper	Morocco	Conceptual	⍰	2019
18	Book chapter	South Africa	Empirical	⍰	2019
19	Conference paper	South Africa	Empirical	⍰	2017
20	Conference paper	Morocco	Conceptual	✓	2019
21	Conference paper	Bangladesh	Empirical	✓	2020
22	Journal article	Netherlands, USA, UAE	Systematic review	⍰	2021
23	Journal article	Spain	Systematic review	⍰	2021
24	Book chapter	South Africa	Empirical	✓	2021
25	Book chapter	South Africa	Empirical	✓	2021

applications would cover eHealth, environmental monitoring, access and traffic control, and digital signage.

(ii) **Jubail Industrial City** (Aina, 2017).

The objective of this project was to improve traffic management, security, quality of public services, and engagement with citizens. It was also funded through a PPP between the Royal Commission Jubail, network operators, and smart city service providers.

(iii) **Lavasa Smart City** (Korachi & Bounabat, 2019).

Lavasa was a private venture launched in 2004 and publicized as India's first smart city. The objective was to develop five self-sustaining towns whose residents would have all their life, work, education, and entertainment needs catered for within the city (Lavasa, 2014). However, its success was slowed down by various challenges, the main one being having to build their own infrastructure from scratch, including transportation and Internet connectivity (Nadhe, 2016).

(iv) **Blockchain-Enabled Vehicle Certification (BVC) Framework** (Das et al., 2020).

BVC is a traffic solution bringing together government and private stakeholders to one platform where each has a unique identification, and they can communicate securely. The system would enable paperless vehicle registration and easy verification of certificates by traffic police, insurance companies, and other parties.

(v) **Smart City Nelson Mandela Bay** (Fashoro et al., 2021).

The Smart City Nelson Mandela Bay initiative involves over 50 stakeholders ranging from government institutions to private companies, civil society, and academic institutions. It is a long-term project with a broad mandate from traffic to energy management. Some of the implementations include a smart mobility system that provides early warnings of road closures when flooding is anticipated. Another implementation monitors dam levels to manage water shortages in the municipality in a more efficient manner. Incubating Great Engineering Minds (iGEMS) is another project that is part of the smart city whose mandate is to train citizens to become smart citizens. Propella is an incubator that supports start-ups developing smart solutions in the municipality. Other implementations include Wi-Fi in public spaces, an online housing application system, and a hub supporting citizens to start businesses online.

(vi) **E-citizen portal in Brasilia** (Bernardes et al., 2018).

The project was aimed at making public services more accessible to all. It featured special devices for the disabled, geo-referenced alerts for relevance to recipients, channels for complaints such as ombudsman services, and live chats for citizen engagement.

(vii) **G2C, G2B, and G2G in 15 Indonesian cities** (Anindra et al., 2018).

G2C refers to government-to-citizens services which include personalized e-notifications from the government and other e-services. It also includes channels

Table 3 Summary of initiatives

Initiative	Country	Funding model	Source
Makkah Smart City	Saudi Arabia	Public-private-partnership	Aina (2017)
Jubail Industrial City	Saudi Arabia	Public-private-partnership	Aina (2017)
Lavasa Smart City	India	Private	Korachi and Bounabat (2019)
Blockchain-enabled Vahicle registration	Bangladesh	Not explicit	Korachi and Bounabat (2019)
Smart City Nelson Mandela Bay	South Africa	Public-private-partnership	Fashoro et al. (2021)
E-citizen participation in Brasilia	Brazil	Public-private-partnership	Bernardes et al. (2018)
G2C, G2B & G2G in 15 Indonesian cities	Indonesia	Not explicit	Anindra et al. (2018)
Smart waste monitoring system	Equador	Not explicit	Veloz-Cherrez et al. (2020)
Sensors for water and soil monitoring	Burkina Faso	Not explicit	van der Hoogen et al. (2021)

for citizens to keep the government aware of their problems, concerns, and opinions. G2B are government-to-business services including legal and administrative support, and keeping businesses updated on events within government agencies that are related to their businesses. G2G is government-to-government services, which entails enhancing interoperability across various government agencies as well as improving capacity of the human resources in government.

(viii) **Smart waste monitoring system** (Veloz-Cherrez et al., 2020).

This prototype was implemented in Riobamba City to monitor waste collection containers and send real-time alerts of waste accumulation and decomposition. The objective was to support the city's efficient collection of waste and contribute toward Ecuador's sustainable development aims and progression toward smart cities.

(ix) **Sensor-based network for water and soil monitoring** (van der Hoogen et al., 2021).

This initiative was deployed by the Aquaculture and Aquatic Biodiversity Research Unit at the Nazi Boni University in Burkina Faso. The sensors monitor the soil and water environment for banana and papaya fields, and fish farms, respectively. The data is used for decision-making by farmers.

Table 3 presents a summary of the initiatives. By geographical distribution, 5 out of the 9 initiatives were in Asia, 2 in South America, and 2 in Africa. The initiatives addressed a variety of smart city needs from mobility, waste and water management, and citizen engagement. Apart from the number of reported initiatives in literature being few, the present ones indicate that developing countries are engaging with the different components of smart cities.

5 Conclusion and Limitations

There are two possibilities that many published initiatives from developing countries may have been missed by this review. The first is the filter to only review articles published in English. There is a significant number of developing countries across the world whose primary language is not English. The second is the variety of terminology around e-government and smart cities. There are many e-government initiatives and not all are smart initiatives, but the distinction is blurry. Despite these limitations, there was still a scarcity of publications even from English-speaking developing countries. The review noted that the number of publications engaging on theoretical discourse around smart cities superseded that of empirical studies reporting on experimental or implemented smart initiatives. There was particularly a shortage of studies from Africa on both papers that contained initiatives and those that did not. Only South Africa and Morocco were represented in the 25 papers reviewed, and only 2 contained an initiative. This shortage has been previously reported by van der Hoogen et al. (2021). Further research could investigate this further to establish whether there are fewer smart initiatives in Africa compared to other developing regions, or it is a case of few academics involved in smart city research hence initiatives exist but are under-reported in publications. Overall, the authors recommend more empirical studies to be conducted to highlight ongoing initiatives in developing countries as a form of knowledge sharing in the quest of advancing together toward sustainable development.

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Greening the Transportation Landscape: Toward Low-Carbon Vehicular Emissions in Ghana

Daniel Nukpezah and Jonathan N. Hogarh

Abstract In Ghana, the road subsector is the dominant mode of transport, accounting for 96% of passenger and cargo traffic. Air quality problems have been exacerbated by the high volumes of old and poorly performing vehicular engines. Also, there are no vehicular emission standards that define acceptable limits for exhaust emissions thereby exacerbating health effects. The present study seeks to model vehicular emissions to provide baseline levels to guide the development of emission standards in the country. Data for analysis were sourced from the customs division of the Ghana Revenue Authority (GRA) and the Driver Vehicle and Licensing Authority (DVLA). The findings are that existing policies have not necessarily discouraged the importation of old cars into Ghana and that the importation of "over-aged" vehicles has not led to environmentally responsible behavior. Modeling of vehicular emissions showed that they are below Euro 2 standard. Vehicular emission projections for 2020 were: CO 298.0, NOx 206.9, VOC 71.7, PM 22.1, and CO_2 18123.7 Gg. To improve air quality, standards for emissions should be developed. Further, fiscal instruments can be used to raise revenue and to address environmental problems. Finally, it was emphasized that policies that provide incentives for new vehicles and use of public transportation could help to reduce the emissions.

Keywords Vehicular emission · Over-aged vehicle · Emissions modeling · Fiscal instrument · Ghana

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1 Introduction

Ghana faces immense challenges with respect to the environment. Air pollution and climate change and their effects have become a global imperative that requires tackling. One area of importance in dealing with air pollution and climate menace is transportation. Concepts such as sustainable transportation and smart mobility have evolved as a first step toward dealing with the nagging air pollution problem across cities and countries. Non-hazardous emissions such as CO_2 (a greenhouse gas that contributes to global warming and its concomitant effects) and hazardous emissions such as carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxide (NOx), and particulate matter (PM) impact the environment. The increasing trend in net greenhouse gas emissions which now puts Ghana in the brackets of nations with positive net CO_2 emission has been reported (GEF/EPA/UNDP, 2011). Although Ghana's emission is lower than many major developing economies, the trends clearly indicated a strong growth potential in the near to medium term horizon as the economy continues to grow. For the period 1990–1996, Ghana was a net CO_2 remover by sinks, by 2000 however, Ghana became a net CO_2 emitter, emitting about 24 Mt. of CO_2-eq in 2006, which amounted to around 1.1 t CO_2-eq per capita (Würtenberger and Tilburg, 2010).

Exposure to hazardous emissions has been identified as a major cause of a wide variety of illnesses including asthma, chronic bronchitis, emphysema, pneumonia, and heart disease (British Columbia Air, n.d.). The United States National Ambient Air Quality Standards identified six criteria pollutants including carbon monoxide, lead, nitrogen dioxide, particulate matter, ozone, and sulfur oxides (US EPA (a), n.d.). Some or all of these pollutants are present in emissions from vehicular, industrial, nautical, and aeronautical combustion engines.

Motor vehicles are the major source of air pollution in many parts of the world. In Ghana, the road subsector is the dominant mode of transport, accounting for 96% of passenger and cargo traffic (EPA, 2017). Although many people have grown to accept the smell of engine exhaust as part of everyday life, there has been an increase in many respiratory and cardiovascular diseases, made worse by air pollution (Afoakwah et al., 2020; Mudu, 2021). Extensive studies across the world have revealed strong links between vehicular emissions and deleterious health problems (Fan et al., 2009; Simoni et al., 2015; Ali et al., 2019; Afoakwah et al., 2020; Mudu, 2021). Carbon monoxide (CO), a poisonous gas emitted from the vehicle's exhaust as a result of incomplete combustion, is a common air pollutant with serious health impacts. Exposure to CO is dangerous because it binds with hemoglobin in the blood to form carboxyhemoglobin which interferes with the blood's ability to carry oxygen to the brain, heart, and other tissues (Washington State Department of Ecology, n.d.). The adverse health effects associated with CO vary with its concentration and duration of exposure. The CO concentrations inside motor vehicles are generally around 10–29 mg/m^3 (9–25 ppm) and occasionally over 40 mg/m^3 (35 ppm). However, short-term peak carbon monoxide concentrations often occur in traffic environments which suggests that the heavier the traffic, the higher the pollution levels. This means regulating the number of vehicles and the speed on the road can be an effective tool to regulate vehicular pollution. Carbon monoxide concentrations up to 57 mg/m^3 (50 ppm) are reported on heavily traveled roads (WHO, 1999). Studies have also shown that CO concentrations of 10 to 100 ppm in ambient air and inside motor vehicles can exert adverse health effects on the general population. Clinical symptoms range from subtle cardiovascular, respiratory, and neurobehavioral effects at low concentrations (10 ppm) to unconsciousness and death after prolonged exposures or after acute exposure to high concentrations of CO (>500 ppm) (Fierro et al., 2011).

Nitrous oxides (NOx) which are compounds of N_2 and O_2 such as NO, NO_2, and N_2O are produced when fuels burn at high temperatures, high pressures, and excess oxygen in the engine combustion chamber. About 50% of NOx emissions worldwide are caused by vehicles utilizing spark and compression ignition engines burning gasoline and diesel, respectively (Jie, 2011). Current scientific evidence links short-term NO_2 exposures ranging from 30 minutes to 24 hours, with adverse respiratory effects including airway inflammation in healthy people and increased respiratory symptoms in people with asthma (US EPA(b), n.d.). Furthermore, NOx reacts with hydrocarbons in bright sunlight to form ozone (O_3), which is one of the most important secondary pollutants in the atmosphere (Donkor, 2015). Children, older people, people with lung diseases such as asthma, and people who work or exercise outside are at risk of adverse effects from O_3. These include reduction in lung function, increased respiratory symptoms, and possibly premature deaths (GEF/EPA/UNDP, 2011).

In Ghana, the air quality problem is exacerbated by the high volumes of old and poorly performing vehicular engines. Coupled with this is the fact that there are no vehicular emission standards that define acceptable limits for exhaust emissions; there are also no baseline emissions for vehicles against which standards could be benchmarked. In the EU however, emission standards exist. For example, emission standards for new vehicles sold in the EU member states are defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards (Stratstone, 2021). The charts (Figs. 1 and 2) illustrate acceptable limits placed on NOx and particulate matter (PM) from Euro 1 standard in 1992 through Euro 5 standard in 2008 for diesel and petrol cars, respectively. Vehicle emission standards and air quality targets were linked with fuel quality parameters implying that emission standards should not be developed in isolation but should be linked with fuel quality parameters. The quality of fuel used is important when it comes to vehicle emissions. Sulfur, which naturally occurs in petroleum fuel is a significant contributor to fuel quality. High sulfur content in fuel significantly reduces the emission reduction effect of catalysts in catalytic converters. Unlike the European Union where the fuel sulfur content limit for Euro one, two, three, four, and five are 2000 ppm, 500 ppm, 350 ppm, 50 ppm, and 10 ppm, respectively, Ghana's regulatory sulfur content for diesel was set at 3000 ppm in 2013 (Ayetor et al., 2020). However, the increasing evidence of the intensifying health damage being caused by air pollution led the Economic Community of West African States (ECOWAS) to which Ghana belongs to come out with a resolution to limit sulfur

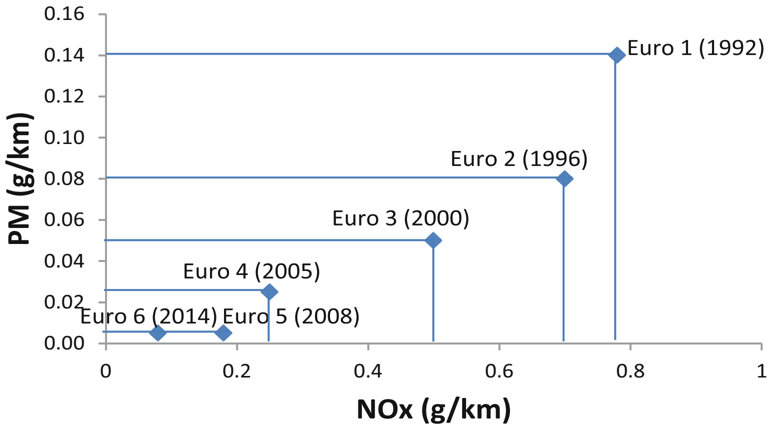


Fig. 1 Chart showing the progression of European emission standards for diesel cars

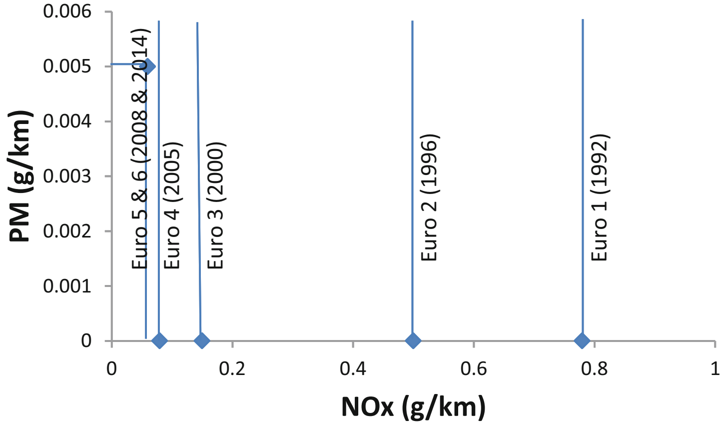


Fig. 2 Chart showing the progression of European emission standards for petrol cars

content to 50 ppm. However, it remained to be seen the extent to which this resolution has been implemented by Ghana. Studies done by Broni-Bediako et al. (2020) suggest that the sulfur content of fuel in Ghana remains 5 times higher than the new guideline value of 50 ppm. Thus to introduce emission standards in Ghana and apply an increasingly stringent standard may require an improvement in the quality of fuel used in the country.

In the EU, emissions of nitrogen oxides (NOx), total hydrocarbon (THC), and non-methane hydrocarbon (NMHC) (the hydrocarbon family of emissions also include volatile organic carbons (VOCs)), carbon monoxide (CO), and particulate matter (PM) are regulated for most vehicle types including cars, lorries, trains, tractors, and similar machinery, but excluding seagoing ships and aeroplanes. For each vehicle type, different standards apply. Compliance is determined by running the engine at a standardized test cycle. Non-compliant vehicles cannot be sold in the EU but new standards do not apply to vehicles already on the roads. No use of specific technology is mandated to meet the standards, though available technology is considered when setting the standards. New models introduced must meet current or planned standards, but minor lifecycle model revisions may continue to be offered with pre-compliant engines (Stratstone, 2021).

The lack of standards exacerbates the health effects of vehicular emissions. Soot and nitrogen dioxide can inhibit breathing in vulnerable people and raises yet to be quantified implications such as health costs and environmental damage. A high proportion of motor vehicle particulate emissions are very fine particles—particles smaller than one micron (PM_1). Particles smaller than 2.5 microns ($PM_{2.5}$)—including PM_1—are now known to be more highly correlated with cardiopulmonary disease and lung cancer mortality (Jie, 2011).

Possible health effects of $PM_{2.5}$ include increased incidence of premature death, primarily in the elderly and those with heart or lung disease; aggravation of respiratory and cardiovascular illness, leading to hospitalizations and emergency room visits for children and individuals with heart or lung disease; decreased lung function and symptomatic effects, including acute bronchitis, particularly in children and asthmatics; increased work loss days, school absences, and emergency room visits.

The World Bank in 1997 estimated that air pollution caused 178,000 premature deaths in urban China in 1995 and valued health damages at nearly 5% of GDP. The same study estimated that hospital admissions due to pollution-related respiratory illness were 346,000 higher than if China had met its air pollution standards, there were 6.8 million additional emergency room visits, and 4.5 million additional person-years were lost because of illnesses associated with pollution levels that exceeded standards. Much of this damage has been attributed to emissions of particulates and sulfur dioxide (Garbaccio et al., 1999).

In an attempt to address the problem of emissions from vehicles and their environmental impacts, the government of Ghana introduced an over-aged penalty on imported vehicles with an age threshold of ten years, which amount increases with the age of the vehicle. The law on over-aged vehicles, as implemented initially in 1998, forbade the import of any motor car that was 10 years old (CEPS Management Law (PNCD Law 330) of 1993). An amendment to this law, which became effective in 2002 (Act 634), allowed the import of such cars but with a penalty. The penalties increased in strata, allowing old motor cars to be imported while maintaining a strong disincentive to import such old cars. While motor cars over-aged by less than 2 years attracted 5% of CIF as a penalty, those over-aged by 2 to less than 5 years attracted 20%. Motor cars over-aged by 5 years and over attracted 50% of the cost, insurance, and freight (CIF) as penalty.

However, it was observed that a high proportion of newly registered vehicles are used ones imported into the country with the number of over-aged vehicles (over 10 years old) showing consistent increases in spite of penalties imposed on them (EPA, 2017). It is thus not clear the extent to which these measures have contributed to curbing environmental pollution. Secondly, vehicle roadworthiness is determined by electrical and mechanical tests and not based on emissions (EPA, 2017). The absence of environmental components in roadworthiness assessment of vehicles in Ghana is partly blamed on the lack of vehicular emission standards in the country as Ghana does not have emission standards that define minimum levels (Nukpezah & Hogarh, 2015). This underscores the need to conduct a study that would provide baseline emission levels against which future trends can be measured and to guide the development of vehicular emission standards. The objectives of this study are therefore to:

- Determine the effectiveness of the policy on over-aged vehicles, on whether it has led to environmentally responsible behavior and lower emissions from vehicles.
- Model vehicular emissions to provide baseline emission levels to guide the development of vehicular emission standards in the country.

Furthermore, the study would provide the evidence base for relevant policy prescription to green the transport landscape which will inure to a "smart city" and avert air pollution and its impacts. Indeed, remedial action must be put in place to reverse the tide by cutting down on hazardous pollutants and increasing greenhouse gas emissions and commit to a developmental model which will yield multiple folds of benefit including socioeconomic prosperity, low carbon and climate resilience economy, and preservation of environmental and cultural integrity.

2 Methodology

2.1 Sources and Type of Data

Data collection for the study is based on multiple secondary sources. This included data from publicly available documents, textbooks, journal articles, internet search engines, consultancy reports, and government agency reports. Particularly, data on vehicle imports and exemptions were sought from the Customs Division of the Ghana Revenue Authority (GRA) while data on vehicle registration and roadworthiness were obtained from the Driver Vehicle and Licensing Authority (DVLA) of Ghana.

2.2 Vehicle Importation and Effectiveness of Policy on Over-Aged Vehicles

Data were collected on the number of vehicles that attracted import duty between 2000 and 2015 (May); the number of over-aged vehicles (vehicles more than 10 years imported into the country); vehicles exempted from paying import tax and the total number of vehicles in "good standing" (registration and renewals) between 2000 and 2014. Vehicle import data were collected from GRA while vehicle data on renewals and roadworthiness were obtained from the DVLA. The data were then projected to 2020 using the yearly rate of increase. The data were entered into excel, analyzed, presented in charts and graphs, and discussed.

2.3 Modeling of Vehicular Emissions

Secondary data were collected and analyzed based on a local study restricted to the Ashanti Region of Ghana. The characteristics of vehicles registered at the various DVLA regional offices are similar across the country. Other relevant factors such as topography, urbanization, and road infrastructure are quite similar across the regional capitals. The emission intensity vehicles are dominated by commercial vehicles such as those known locally as "trotro," poorly maintained taxis and other private vehicles. The various regions have their fair share of these emission intensity vehicles. In view of this, the data from the Ashanti Region were considered as representative for the country. Vehicular emission modeling was based on the study by Agyemang-Bonsu et al. (2010), who modeled vehicular emissions in the Ashanti region (2000–2005) applying COPERT III software. It was the first modeling of vehicular emissions in Ghana and it was based on traffic-driven data (vehicular speed, mileage, fleet population, fuel consumption and quality, and meteorological data). Given that the region has about 20% of the vehicular fleet of Ghana (Nukpezah & Hogarh, 2015), we scaled up the emission projections to cover the entire country. We applied appropriate polynomial functions to project emissions for subsequent years up to 2020 with the baseline year of 2000 as year 1. We then estimated the yearly vehicular emissions in Ghana from 2000 to 2020. In order to obtain the minimum emission levels (in g/km) for the various pollutants, we assumed Euro 2 standards (based on the largely second-hand vehicles imported into Ghana). Our assumption is against the backdrop that, in an assessment by the International Council on Clean Transportation (ICCT) regarding the impact of stringent fuel and vehicle standards on premature mortality and emissions, a baseline assumption of emission standards for sub-Sahara Africa was set at Euro 1 in 2005 and Euro 2 in 2015 for light-duty vehicles (LDVs) (Chambliss et al., 2013). The move to Euro 2 was only driven by the higher market availability of vehicles imported to Africa meeting post-Euro 1 standards. The timeline for heavy-duty vehicles (HDVs) was set at Euro 1 in 2005, with no further progress thereafter.

Further, to examine whether vehicular emissions in Ghana averagely met these standards, the projected emissions in Gg were converted to g/km applying the following formula:

$$\text{Average Emissions}\ (\text{g/km}) = \frac{\text{Emissions}\ (\text{Gg}) \times 10^9}{\text{FP} \times 365\ \text{days} \times \text{AMPD}} \quad (1)$$

where

FP Fleet population
AMPD Average mileage per day (km/day)

Tables and appropriate graphs were derived for the data collected and the results presented and discussed.

3 Results

3.1 Licensing and Road Worthiness of Vehicles

A total of 1,197,601 vehicles were registered in Ghana from January 2005–May 2015 according to the data obtained at the Driver, Vehicle, and Licensing Authority (DVLA) in Ghana. By category, the motorcycles constituted the highest number of vehicles registered (totaling 365,841) for obvious reasons that they are more affordable. Among the motor vehicles, those with engine capacity up to 2000 cc appeared preferable with a total of 453,174 registrations compared to 190,956 registered vehicles with engine capacity above 2000 cc. This is because of the relatively reduced cost of running the lower engine capacity motor vehicles. It presupposes that peoples' behavior regarding the acquisition of motor vehicles was partly influenced by the potential running cost of the motor vehicle.

The fleet of vehicles considered to be roadworthy in Ghana rose from 350,016 in 2000 to 878,639 in 2014. It was projected that this fleet reached approximately 1.3 million in 2020 (Fig. 3). This puts Ghana ahead of many of the countries in the sub-region such as Burkina Faso, Cameroon, Gabon, Sierra Leone, and several other countries in terms of per-capita vehicle ownership. Indeed, without the inclusion of environmental components in roadworthiness assessment, this rising number of vehicles on the road certainly has implications for gaseous and particulate pollution of the atmosphere.

3.2 Importation of Vehicles

Ghana has two levels of environmental fiscal controls governing vehicular imports. The first control is a tax system graduated by engine capacity, such that vehicles with bigger engines attracted a greater fraction of the cost, insurance, and freight (CIF) as duty and vice versa. Motor cars with a cylinder capacity not exceeding 1900 cc attract 5% of CIF as import duty (Nukpezah & Hogarh, 2015). Those with a cylinder

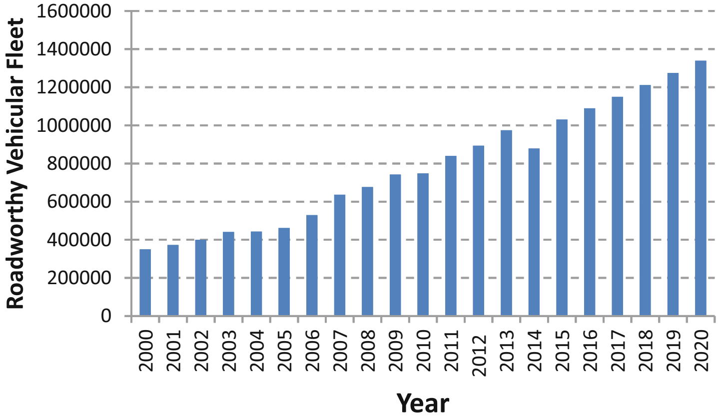


Fig. 3 Projected growth in total roadworthy vehicles in Ghana

capacity exceeding 1900 cc but not exceeding 3000 cc attracted 10% of CIF as duty, while those with capacity above 3000 cc attracted 20%. Motor vehicles designed to carry ten (10) or more persons (e.g., buses and coaches) attract 5% of CIF as duty, while those designed to carry thirty or more passengers are exempted as a form of encouraging mass transportation system in the country. Similarly, motorbikes, ambulance, hearse, and other special-purpose vehicles are exempted from import duty. Motor vehicles for the transport of goods such as trucks and tippers attract 5% duty, despite their high cylinder capacity. Invariably, the import duty system on vehicles was structured to discourage the import of high polluting vehicles, considering that those with greater cylinder capacity potentially consume more fuel and produce more carbon dioxide and other emissions.

The second level of environmental fiscal control is in the form of penalties imposed on vehicles that are more than 10 years old (described as over-aged vehicles). As already noted, the law on over-aged vehicles, as implemented initially in 1998, forbade the import of any motor car that was 10 years old (CEPS Management Law (PNCD Law 330) of 1993). An amendment to this law, which became effective in 2002 (Act 634) (CEPS, 2016), allowed the import of such cars but with a penalty. Thus, imported vehicles more than 10 years are considered over-aged. The penalties increased in strata, allowing old motor cars to be imported while maintaining a strong disincentive to import such old cars. While motor cars over-aged by less than 2 years attracted 5% of CIF as penalty, those over-aged by 2 to less than 5 years attracted 20%. Motor cars over-aged by 5 years and over attracted 50% of CIF as penalty. However, there are no incentives or subsidies associated with the importation of brand-new vehicles and vehicles that pollute less.

3.3 *Effectiveness of the Policy on Over-Aged Vehicles*

Although not explicit, it is assumed that the policy on over-aged vehicles was put in place as the first line of safeguards against the import of high polluting motor cars into the country. The relatively greater import duty imposed on cars with greater cylinder capacity should discourage the import of fuel-guzzling engines. This purpose appeared to have been achieved considering that the yearly imports of vehicles (i.e., those that attracted import duty) were dominated by vehicles with engine capacity not exceeding 1900 cc (Fig. 4).

On average, there has been a progressive increase in the number of over-aged vehicles imported into Ghana between 2004 and 2014 (Fig. 5). It increased from 4338 in 2004 to a high point of 55,562 over-aged vehicles in 2013. The number of over-aged vehicles decreased afterward in 2014 to 28,956. It has been suggested that the dip in the number of over-aged vehicles and vehicles that attracted import duty in 2014 was due to the removal of subsidies extended to certain categories of workers

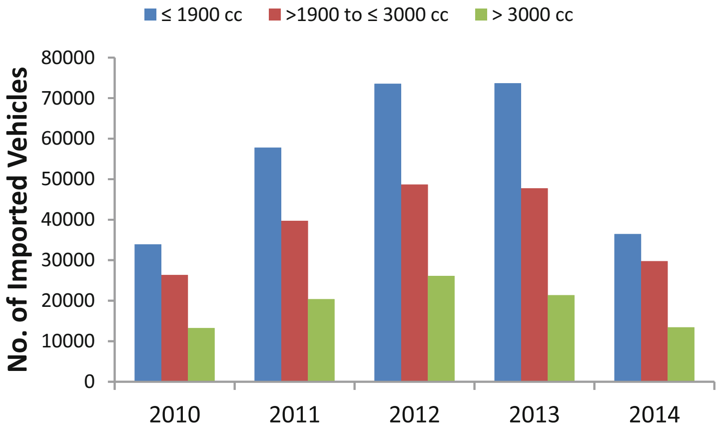
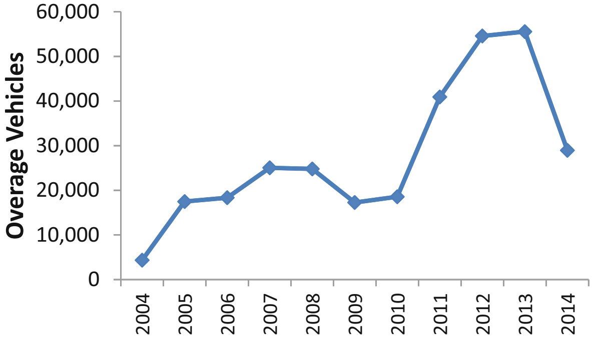


Fig. 4 Annual imports of vehicles that attracted import duty into Ghana

Fig. 5 Over-aged vehicles imported into Ghana from 2004 to 2014



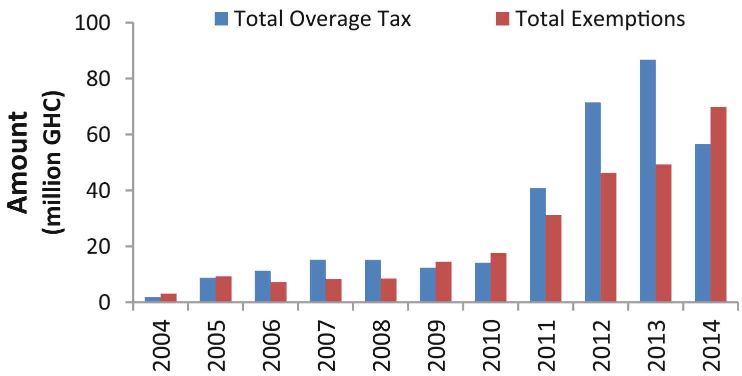


Fig. 6 Total over-aged tax and amount lost in exemptions concerning the importation of over-aged vehicles

such as medical doctors and other healthcare workers, and university lecturers, with regard to vehicle importation.

Indeed, the over-aged vehicle policy has not necessarily led to environmentally responsible behavior nor discouraged the importation of old cars into Ghana. For example, while the restriction on the importation of over-aged vehicles chalked some success in terms of reducing over-aged vehicle imports, this success was short-lived. Between 2000 and 2006 there was a slight decrease in the contribution of the energy sector including transport to total greenhouse gas emissions (GEF/EPA/UNDP, 2011). This has been explained as due possibly to the increasing importation of fairly new vehicles with less CO_2 emissions into Ghana as a result of government policy on importation of used vehicles, which imposes an import duty penalty on over-aged vehicles. However empirical studies suggest that while the ban resulted in a reduction in the number of used car imports, the reduction was not significant and did not achieve its prime objective of reducing air pollution in Ghana. It is possible that the huge amount of exemptions (see Fig. 6 below) contributed toward the policy on over-aged vehicles not achieving its objectives (Iddisah, 2012).

The revenue from the penalties on over-aged vehicles rose exponentially partly due to the progressive increase in the number of imported over-aged vehicles during this period (Fig. 6). The exemptions granted was however strikingly high. In some years (i.e., 2004, 2005, 2009, 2010, and 2014), the amount lost in exemptions was greater than the revenue received as an over-aged penalty. In other years, the exemptions far exceeded 50% of the revenue accrued in over-aged penalties. It has been suggested that some of these exemptions arose as a result of auctioning of vehicles that importers could not pay the requisite taxes and penalties for. Such vehicles put on auction were exempted from paying the penalty. Exemptions granted to certain categories of public sector workers may have also reduced the impact of the penalty on such importations. These exemptions might have encouraged the yearly rise in the import of over-aged vehicles.

3.4 Modeling of Vehicular Emissions

As noted earlier, based on the initial model of Agyemang-Bonsu et al. (2010), we projected vehicular emissions for the entire country up to 2020 applying appropriate polynomial functions, with the baseline year of 2000 as year 1. The following amounts of vehicular toxic emissions were projected by the end of 2020: CO 298.0, NOx 206.9, VOC 71.7, PM 22.1, and CO_2 18123.7 Gg, respectively (Fig. 7). Currently, Ghana does not have vehicular emission standards. However, if we should assume Euro 2 standards (based on the largely second-hand vehicles imported into Ghana), then emissions from petrol engines should not surpass 2.20 g/km CO and 0.50 g/km (HC + NOx) (in the emission model, the hydrocarbons estimated were VOCs); no criterion was set for the remaining toxic pollutants. For diesel engine vehicles, however, Euro 2 standards suggest the setting of emission limits for CO (1.00 g/km), HC (0.15 g/km), NOx (0.55 g/km), and PM (0.08 g/km).

Applying Eq. 1, average vehicular emissions (g/km) of the pollutants were estimated and reported in Table 1.

From Table 1, it is clear that vehicular emissions in Ghana have never met European emission standards for CO, NOx, and VOCs even at the Euro 2 level, which was set for Europe as far back as 1996. The levels of PM in vehicular

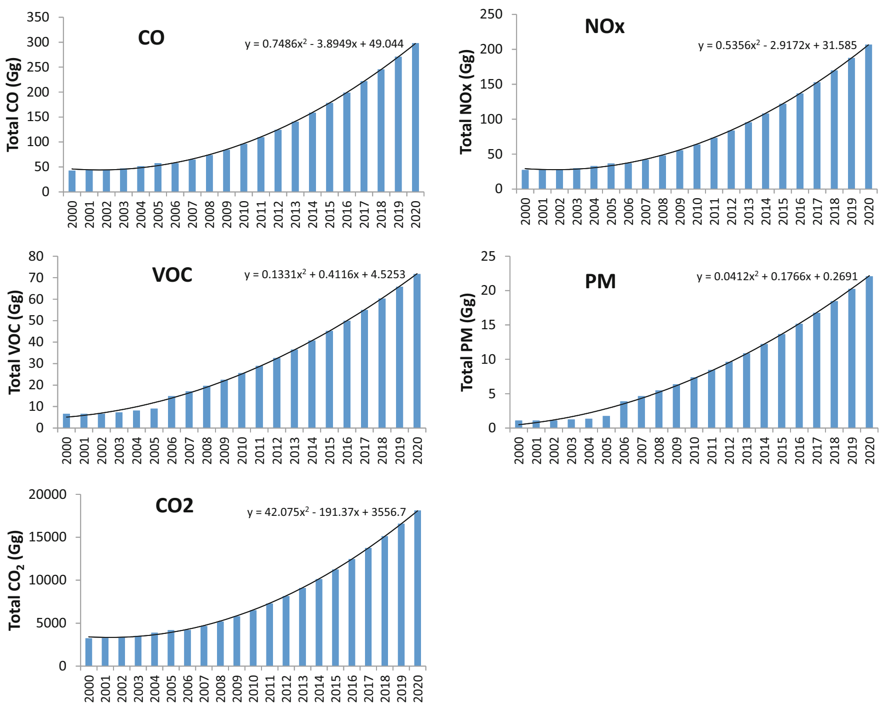


Fig. 7 Projected total emissions of CO_2, CO, NOx, VOC, and PM from vehicles in Ghana

Table 1 Estimated yearly vehicular emissions in Ghana from 2000 to 2020

Year	Average Emissions (g/km)				
	CO_2	NOx	VOCs	CO	PM
2000	249.5	2.09	0.51	3.29	0.08
2001	233.0	1.94	0.47	3.11	0.08
2002	222.9	1.79	0.44	2.90	0.07
2003	210.8	1.79	0.44	2.81	0.07
2004	211.6	1.79	0.44	2.80	0.07
2005	204.7	1.79	0.44	2.81	0.09
2006	205.8	1.80	0.73	2.81	0.19
2007	204.9	1.84	0.75	2.85	0.20
2008	205.4	1.91	0.78	2.92	0.22
2009	207.0	1.98	0.80	3.00	0.23
2010	209.2	2.05	0.82	3.09	0.24
2011	212.0	2.13	0.84	3.19	0.25
2012	214.9	2.21	0.86	3.28	0.25
2013	218.1	2.29	0.88	3.37	0.26
2014	221.3	2.36	0.89	3.47	0.27
2015	224.5	2.43	0.90	3.55	0.27
2016	227.7	2.50	0.91	3.64	0.28
2017	230.8	2.56	0.92	3.72	0.28
2018	233.8	2.62	0.93	3.80	0.29
2019	236.7	2.68	0.94	3.87	0.29
2020	239.5	2.73	0.95	3.94	0.29

emissions in Ghana were however within the Euro 2 standards in 2000 to 2004, but thereafter exceeded the limit of 0.08 g/km. So clearly, vehicular emissions in Ghana presently do not meet minimum emission standards applying the Euro 2 as a guide. Given the environmental health implications of these emissions, it is important that local emissions standards are developed as quickly as possible for testing of vehicular emissions to commence in Ghana as part of the vehicle registration and roadworthy renewal processes.

4 General Discussion

To effectively regulate vehicular emissions, some authorities have resorted to a fiscal instrument to raise revenue and to address environmental problems. For example, in 2009 the South African government announced a reform of the ad valorem excise duty on motor vehicles to include a CO_2 emissions component. A threshold of 175 g/km was agreed for the double cab (4 × 4 vehicles), above which a tax rate of R100 for every g/km should be applied (National Treasury of South Africa, n.d.). The CO_2 emissions for passenger cars were set at 120 g/km and a tax rate of R75 for every g/km above this threshold. Other vehicles (light commercial vehicles, heavy-duty vehicles) were not immediately roped into this new tax system. Minibus taxis were excluded from this tax as they were predominantly used for public transport. However, the position of minibus taxis is expected to be reviewed when all other light commercial vehicles become subject to the CO_2 vehicle emissions tax.

Assuming the South African thresholds in the Ghanaian context, it is evident that the emissions in Ghana fall short of these thresholds, with the current (2020) average CO_2 vehicle emissions estimated at 239.5 g/km (Table 1). If we apply the South African threshold of 175 g/km CO_2 vehicle emissions across board in Ghana, then on average, there would be an excess of 64.5 g/km, i.e. (239.5–175 g/km) that could be levied. Proposing a conservative levy of GH¢ 6.00 (about US 1$) for a gram of excess CO_2 emitted per km, which is far below the rate of R75 (approximately US$ 5) per gram of excess CO_2 levied with respect to passenger cars in South Africa, would constitute a modest starting point for vehicular CO_2 emission levy in Ghana. At this conservative rate and assuming that three-fourth of the fleet emitted in excess of the emission threshold (considering the large second-hand fleet of vehicles in Ghana), the excess 64.5 g/km could generate up to 64.5 × 6.00 × 1,555,125 = GH¢601,833.375. (Note: the estimated fleet for 2020 is 2,073,500 and three-fourth of this figure is 1,555,125). An administrative arrangement can then be made to remit the generated funds into an appropriate fund, to support environmental pollution control work.

Several other best practice models have been reported in the literature. For example, the use of fuel with low sulfur content reduces emissions. On the other hand, the use of fuel containing a significant amount of sulfur (above 10%), reduces the working effect of a catalytic converter and thereby resulting in higher emissions. Euro five emission standard ensures significant reduction in PM emissions (Ayetor et al., 2020). Thus adopting a fuel quality standard of low sulfur content is one sure way of reducing vehicular emissions.

Climate and emissions concerns have resulted in the increased use of electric vehicles especially in advanced economies with many of such countries looking to ban the sale of gas and diesel powered vehicles from 2030 and beyond. In Ghana, as of 2019, only 2 pre-owned electric vehicles have been imported into the country and there are just about 20 hybrid-electric vehicles in the country all of which were imported as second-hand vehicles (Ayetor et al., 2020). This number is insignificant compared to the total number of registered vehicles. Skill gap in electric vehicle maintenance, non-availability of spare parts, charging infrastructure, and the initial price of electric cars are the main challenges to overcome to boost electric vehicle penetration in Ghana and other countries in Africa. Although, in its 2019 budget, the Ghana government announced the promotion of fully electric and hybrid-electric vehicles as one to help achieve the Sustainable Development Goal (SDG) in climate change, currently, there is still not a ready policy underpinning the adoption of electric vehicles in Ghana.

In order to reduce the impact of vehicular emissions on urban air quality, Beijing in China adopted several vehicle emission control strategies and policies since the mid-1990s. These strategies and policies included adopting a series of European emission standards for new light-duty vehicles (LDV) and new heavy-duty vehicles

(HDV), enhancing the annual inspection and maintenance (I/M) program, improving fuel quality, scrapping high-emitting vehicles, and more. In addition, many temporary transportation control measures were implemented during the summer of 2008 for the 2008 Olympic Games in Beijing. As a result, a significant reduction in vehicle emissions, as well as improvement of overall air quality, was achieved during the period (Wu et al., 2011). Some of the emission control strategies and policies used by Beijing included the following: (1) Emission control on new vehicles; (2) emission control on in-use vehicles; (3) fuel quality improvements; (4) alternative fuel and advanced vehicles; (5) economic policies including fiscal incentives and vehicle emission taxes/fees; (6) public transport; and (7) temporal traffic control measures (Wu et al., 2011). Major traffic controls were implemented including the fact that (1) Private vehicles could only operate on odd or even days depending on the last digit of their license plates. This was implemented and enforced and was an important driver for many people using public transportation (2). 70% of government vehicles were ordered off the road during the event (3). Beijing instituted a labeling program with green labels given to low polluters to put on their windscreen. High-emitting vehicles had yellow labels. Most vehicles with yellow environmental labels were banned from the roads throughout Beijing during the games. As a result, total urban vehicle kilometers traveled (VKT) was reduced by 32.0% during the Games. Traffic eased considerably and the average speed weighted by grid VKT increased from 25 km h^{-1} to 37 km h^{-1} during the Games. Consequently, vehicle emissions of VOC, CO, NO_X, and PM_{10} inside Beijing during the 2008 Olympics were reduced by 55.5%, 56.8%, 45.7%, and 51.6%, respectively, relative to the inventory before the Olympics (Wu et al., 2011). This suggests that a shift to the use of public transportation with fewer private vehicles can be a panacea in tackling pollution due to vehicular emissions. In 2008, a demonstration program was introduced in Beijing in which drivers were restricted once a week from driving their car based on the license plate. This resulted in many patronizing public transport with a cumulative effect in moderate reduction in vehicle emissions (Wu et al., 2011).

In Jakarta, Indonesia, the purchase of diesel passenger cars was discouraged since diesel cars pollute more than petrol cars, through fiscal policies by setting a higher sales tax rate for diesel fuel to disincentivize the purchase of diesel cars. Conversely, the sales tax rate for gasoline was lowered and this created opportunities to reduce vehicle emissions in Jakarta (ICCT, 2014).

In Hong Kong, petrol and LPG vehicles were required to undergo an emission check during their annual roadworthiness test. The Environmental Protection Department operated a Smoky Vehicle Control Program that required smoky vehicles spotted by accredited spotters to undergo a dynamometer smoke test within a specified period. Failure to pass the test resulted in the vehicle license being canceled. It was reported that the new initiatives in Hong Kong brought some improvements in roadside air quality. Compared with 1999, the roadside concentrations of some of the major air pollutants dropped by 2011: respirable suspended particulates (RSP), sulfur dioxide (SO_2), and nitrogen oxides (NO_X) have been down by 33%, 56%, and 28%, respectively, and the number of smoky vehicles spotted also reduced by about 80% (Hong Kong Environmental Protection Department, n.d.).

The aforementioned models of management of vehicular emissions present good practices from developed, developing, and transition economies. The important aspects of these models include adoption of high fuel quality and electric vehicle use, traffic management, environmental tax on petroleum, and other fiscal controls on the direct emissions from vehicles. Interestingly, environmental tax on petroleum has been gradually applied in Ghana since 1989 (Kombat & Watzold, 2018). Thus, the capacity exists to utilize this approach of vehicular emission abatement in Ghana and would require maximization of implementation strategies for pollution control. Regarding fiscal control on vehicular emissions, technical capacity may be required to measure emissions during the renewal of the roadworthy of vehicles, to form the basis for imposition of levy on polluting vehicles. Beyond certain thresholds, renewal of roadworthiness for vehicles may be refused. The third model, which are traffic control measures could be encouraged in Ghana by promoting public transport and improving the road infrastructural system.

5 Conclusion

The study has established that the policy on the importation of over-aged vehicles has not necessarily discouraged the importation of old cars into Ghana and it cannot conclusively be said that the importation of over-aged vehicles has led to environmentally responsible behavior. This may be explained as due to the high number of exemptions observed which likely did not discourage people from importing. The high import duty exemptions likely defeated the purpose of the policy and resulted in the importation of over-aged vehicles into the country contrary to expectations. The policy on over-aged vehicles also does not address the fact that there may be vehicles that are less than 10 years but emit excessive CO_2 and other pollutants, and vice versa. Further, modeling of vehicular emission to cover the entire country based on an initial regional study showed that vehicular emissions in Ghana are below Euro 2 standard (meaning that emission standards are lower than what pertained in Europe in 1996). Projections for vehicular emissions for 2020 were: CO 298.0, NOx 206.9, VOC 71.7, PM 22.1, and CO_2 18123.7 Gg. Given the environmental health implications of these emissions, it is important that local emissions standards are developed as quickly as possible for testing of vehicular emissions to commence in Ghana as part of the vehicle registration and roadworthy renewal processes.

In order to improve vehicular air quality, several options from international best practices are available and should be considered for adoption. First, there is the need for the country to develop vehicular emission standards. The findings of this study can serve as baseline emission levels for consideration. In addition, traffic management through a deliberate policy of incentivizing the importation of buses for use in urban areas improved fuel quality, a policy framework for the adoption of electric vehicles and environmental fiscal policies such as emission tax should be considered. It has been demonstrated that if such tax were applied, retrospectively, Ghana could have raised GH¢ 601,833.375 (over US$ 100,000,000) in year 2020 to support environmental pollution control work. Finally, incentives for public transportation use and policies that encourage the use of pollution control technologies to reduce emissions emanating from vehicles should be given the necessary attention.

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The Socio-Technological Value to Stakeholders of Smart City Initiatives That Address Urbanization Challenges

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Abstract The Covid-19 pandemic impacted cities and exposed the issue of urban vulnerability to pandemics. Smart Cities focus on using technological solutions to address these urbanization challenges by augmenting basic city infrastructure. The purpose of this paper is to report on an investigation conducted to answer the research question, "*What is the socio-technological value to stakeholders of Smart City initiatives that address urbanisation challenges?*" A case study approach was applied to this study using five cases of Smart City initiatives in the Eastern Cape province of South Africa. Semi-structured interviews were conducted with stakeholders in these initiatives. The Qualitative Content Analysis process was followed to analyze the interview data according to socio-technical factors that measure the value of initiatives to stakeholders. The contribution of this chapter is the set of factors that can be used to determine the socio-technical value of Smart City initiatives, thereby providing support for more efficient decision-making. The socio-technical factors related to the economy, the environment, and living conditions. The main economical factors identified were *attracting investors* and *reduction of costs*. For environmental value, the factors were mostly related to resource management, navigation, and mobility. Other socio-technical factors identified were *employment and skills development, ICT infrastructure*, and *service delivery*.

Keywords Smart Cities · Stakeholder value · Smart City factors · Socio-technological value · Urbanization

1 Introduction

Rapid urbanization creates several challenges within cities, many related to infrastructure, such as transportation, water, housing, healthcare and sanitation (Estevez et al., 2016). The increased activities and amplified energy consumption in cities

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have also led to a subsequent increase in environmental pollution. In Africa, urbanization is usually the result of the population seeking refuge from rural conflict and degradation, which leads to economic challenges due to migration outpacing the creation of formal work (Mboup & Oyelaran-Oyeyinka, 2019). This lack of formal work availability has led to an increase in informal work in the cities and in some cases a rise in crime. The recent Covid-19 pandemic has underscored these challenges in urbanization and magnified deficiencies in the way cities are designed, built and managed (Acuto, 2020).

City population density, especially in areas of living and transportation, led to the rapid spread of the Covid-19 virus and high death rates in megacities worldwide (Desai, 2020). The healthcare infrastructure in these cities could not keep pace with the high infection rates of the population. The effects of the pandemic were more evident in cities as top global metropolitan areas had the highest infection and death rates (Kakderi et al., 2021). The pandemic also catalyzed a shift in urban mobility due to governmental requirements of social distancing, working from home and restricting international travel (Arimura et al., 2020). In response to government policies surrounding the pandemic, Smart City initiatives have accelerated, with many cities around the world becoming digitized (Kakderi et al., 2021). Costa and Peixoto (2020) argue that due to Covid-19, the world witnessed one of the worst economic and social crises, and the answer to future crises is robust, proactive and integrated Smart Cities. Cities can be viewed as socio-technological systems where the social, economic, political and technological aspects are interlinked and affect one another (Finger, 2021). In this chapter, the social aspect will also include the economic and political aspects. Smart City solutions include socio-technological systems such as smart transport, energy, buildings and healthcare (Kumar et al., 2020).

The Kantian Capitalism theory states that all stakeholders have a right to participate in the direction of that in which they have a stake (Evan & Freeman, 1988). Therefore, it is recommended that adequate information and feedback regarding Smart City initiatives should be provided to stakeholders. However, few studies have reported on this feedback. In addition, most Smart City initiatives are expected to provide non-tangible benefits or value for stakeholders, such as liveability, sustainability, and knowledge—with the main goal of these initiatives being to improve citizens' living conditions. However, the actual value of Smart Cities to stakeholders who visit, live, work and invest in them has not been extensively explored or reported on. This gap in empirical reports of Smart City initiatives can affect the decision-making of Smart City stakeholders regarding their choice of visiting, living, working, and investing in these cities. This chapter addresses these gaps and answers the research question: "*What is the socio-technological value to stakeholders of Smart City initiatives that address urbanisation challenges?*" The Smart City dimensions proposed by van der Hoogen et al. (2019), the value realization theory proposed by Flak et al. (2015) and other value theories were adopted in this research to understand and demonstrate how stakeholders can assess the value realized from Smart City initiatives and to make decisions on how to improve or terminate such initiatives.

This chapter is structured as follows: Sect. 2 reviews the theories and literature related to value, Smart City initiatives, and the socio-technological value of these initiatives on stakeholders. Section 3 describes the research methodology, i.e., the Framework for Integrated Methodologies (FraIM), and the related research design used to answer the research question. The findings from the interviews are reported in Sect. 4. Discussions are made based on the findings from the interviews and the literature in Sect. 5. The final recommendations for socio-technological factors for decision-making are made in Sect. 6.

2 Theories and Literature Used to Guide the Research

Flak et al. (2015) applied the Sarker et al. (2012) framework in Norway as a guide for achieving co-created value, and for identifying factors that could affect value co-creation in Smart Cities as well as the stakeholders who should be involved. In these studies, the terms "benefits" and "value" are used interchangeably. Therefore, if something has a positive benefit then it has value. A similar interpretation was adopted for this study. The Flak et al. (2015) framework was therefore used in this research to guide the data collection from Smart City stakeholders, and has five phases for a Smart City initiative for the co-realization of value (or benefits). These phases are identified as follows:

- Phase 1—*Articulate benefits*. This phase explores existing and potential benefit areas for services with the help of the service owner.
- Phase 2—*Plan benefits realization.* This phase involves elaborating ideas into a detailed benefits plan with actionable steps to ensure that the benefits are realized.
- Phase 3—*Implement plan.* Implement the benefit plan from phase 2.
- Phase 4—*Measure benefits realized*. The service owner has to measure the benefits according to the measurements from the benefit plan and report these findings.
- Phase 5—*Evaluate benefits, gaps, and needs*. Reports from all service owners are evaluated and corrective measures are taken where delays in services are evident.

Another concept related to value is "impact." For the purposes of this study, if an initiative has a positive impact then it has benefit or value. Bond et al. (2016) argue that social, economic and environmental impact can be measured according to how strong, weak, direct, indirect, positive, neutral or negative the impact is based on the following related factors: economic prosperity, public budgets and services, consumption, health and longevity, education, climate, and energy and natural environment. According to Sopact (2021), social impact *"is all about the change that you create for a stakeholder*" and corporations are realizing that shared value for all is created through stakeholder engagement from both a social and business value perspective. To understand what stakeholders want or value, their input at an economic level is considered important especially for socio-technological solutions.

Table 1 Success factors of socio-technological value of Smart City initiatives

Social value		
Smart economy: • Economic image and trademarks • Entrepreneurship • Flexibility of labor market • Innovative spirit • International embeddedness • Productivity	**Smart environment:** • Attractiveness of natural conditions • Environmental protection • Future proof • Pollution • Sustainable resource management	**Smart living:** • Cultural facilities • Health conditions • Individual safety • Housing quality • Education facilities • Touristic attractiveness (smart tourism) • Social cohesion
Technological value		
Smart technology and ICT infrastructure: Smart technologies; smart data; availability of ICT infrastructure		

In this chapter, the socio-technological value of Smart Cities is represented by four of the Smart City dimensions proposed by van der Hoogen et al. (2019), which include Smart Technology and ICT Infrastructure, Smart Economy, Smart Environment, and Smart Living. Each dimension has several related success factors. These factors can be used for planning or measuring the success of Smart City initiatives. The Smart Technology and ICT Infrastructure dimension represents the technological value and considers the three factors, namely the available IT/ICT infrastructure, the technologies used, as well as the use of data in a Smart City. The other three dimensions represent the social aspect of value. The first of these dimensions, Smart Economy, focuses on economic competitiveness and has factors such as innovation, entrepreneurship, productivity, and integration with national and international markets (Giffinger et al., 2007). The second dimension, namely the Smart Environment, relates to environmental protection and attractive natural conditions such as green spaces, pollution and resource management. Lastly, Smart Living refers to the quality of life in the city and includes factors such as culture, tourism, health, housing, and work life. The factors are summarized in Table 1.

3 Research Design and Methodology

The research design for this study was structured according to FraIM, proposed by Plowright (2011), who uses the concept of mixed methods for planning and designing empirical research.

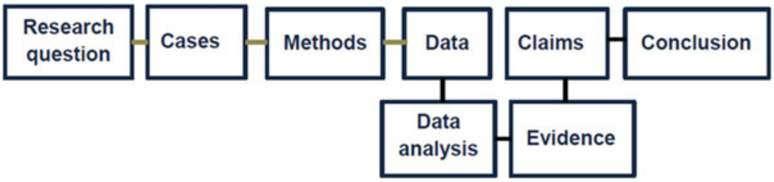

Fig. 1 The basic structure of the FraIM (Plowright, 2011)

3.1 FraIM Methodology

FraIM consists of a basic structure with eight components (Fig. 1), where the research question is the first component. Plowright (2011) argues that if the research question is established, then decisions about the content for the other components should follow. These include selecting the cases and the methods, and data for data collection and analysis. Claims can then be made based on the evidence and conclusions can be formed.

3.2 The Cases and Participant Profiles

The Eastern Cape is the poorest province in South Africa with the highest unemployment rates, which has led to a lower quality of education and unskilled workers (Ngumbela, 2021). The two cities in this province that served as the cases (second FraIM component) for the research were the Nelson Mandela Bay (NMB) and Buffalo City. This chapter reports on a second round of interviews with stakeholders of Smart City initiatives in these two cities. Round 1 was reported on in an earlier study by van der Hoogen et al. (2021), where the following five types of initiatives were identified:

- Initiative 1: Smart Communities
- Initiative 2: Smart Manufacturing and Engineering
- Initiative 3: Smart Parks and Industrial Development Zones (IDZs)
- Initiative 4: ICT Industries
- Initiative 5: Research and Education

The Round 1 gatekeepers were approached to give contacts for possible utilizers and/or users of their initiatives and 21 contacts were provided. Table 2 summarizes the providers of the 16 participants (P7 to P22) who agreed to take part.

In van der Hoogen et al. (2019), different roles and types of Smart City stakeholders were identified. The first role was that of citizens. In Round 2, four of the participants represented the stakeholder role of citizens (P12, P13, P15, P16) and were part of Initiative 1. The remaining 12 participants represented the stakeholder roles of users or providers or both, where three of them also represented Initiative 1, whilst two represented Initiative 2 and three represented Initiative 3. Only one

Table 2 Profile of round 2 interview participants (van der Hoogen, 2021)

P#	Participant job description	Initiative/case	Stakeholder role	City
P10	Enterprise engineering manager (incubator)	Initiative 1 (Smart communities)	Provider	NMB
P17	Head of Connected City			
P19	General manager for electricity and energy services		User/provider	Buffalo City
P8	ICT IoT cyber security maintenance department: automotive manufacturing	Initiative 2 (Smart manufacturing and engineering)	User	Buffalo City
P9	Entrepreneur—engineering software solutions		Provider	NMB
P18	IT manager: software applications and business processes	Initiative 3 (Smart parks and IDZs)		
P20	Technology-related technical services		User/provider	Buffalo City
P21	Technical advisor for Smart City initiatives		Provider	
P22	ICT manager	Initiative 4 (ICT industries)	User/provider	
P7	Program manager—innovation through engineering	Initiative 5 (Research and education)	User/provider	NMB
P11	Sustainability manager—infrastructure service & space operations			
P14	Head of department at a university			
P12	Administrator and entrepreneur	Initiative 1 (Smart communities)—citizens	User	NMB
P13	Fiber installer and WiFi forum custodian		User/provider	
P15	Student		User	
P16	Pharmaceutical business coach and professional trainer		User/provider	

participant represented Initiative 4, who was an ICT Manager at the Buffalo City Metropolitan Municipality (BCMM). Three participants represented projects in Initiative 5 related to research and education and were from the Nelson Mandela University.

3.3 Data Collection and Analysis Process

Methods are the third FraIM component, and the methods used in this study were a literature review and interviews. The aim of the study, the interview question guide, the classification of stakeholders, and a formal letter with ethics information were emailed upon indication of a participant's interest in the interview. The eight steps of the Qualitative Content Analysis (QCA) process, recommended by Schreier (2013), were followed for data collection and analysis, and are summarized in Appendix.

Plowright (2011) promotes warrantable research (also referred to as valid or authentic research) through following the FraIM methodology, and reporting, in detail, the processes and steps for each component. Ensuring validity through triangulation was done by adopting the approaches of Guion (2002). The first approach, namely data triangulation, was conducted by analysis and triangulation of data from interviews with each stakeholder group. For investigator triangulation, different coders were used to check the coding frame. Lastly, for methodological triangulation, both narrative and numerical methods were used. Further strategies were used to ensure the reliability and validity of this research. Coding consistency (independent parallel coding) (Thomas, 2006) was one such strategy, and the different sets of codes and themes were compared to eliminate any overlapping. Three coders checked the raw data using a coding framework as part of the QCA process. Two independent coders selected which sample quotes to include from the interviews. Chain of evidence was the second strategy used to ensure reliability throughout the study (Yin, 2014). This chain was built through collecting, confirming and sharing information with the participants, and included checking the objectives of the study and interview structure before the interview process. Ethical consideration was adhered to, and ethics clearance related to this study was obtained (reference no. REF-H18-SCI-CSS-004).

The fourth FraIM component represents the actual interview data collected and relates to the types of data from transcription documents/artefacts, which in this study consisted of narrative interview data. In the fifth FraIM component, the data were analyzed numerically and narratively, and codes, themes and sub-themes were identified.

The last three components of FraIM are reported in the following three sections. The evidence, which is the sixth component, is discussed in Sect. 4. The seventh component represents the claims and is presented in Sect. 5. The final component, namely the conclusions, is presented in Sect. 6.

4 Evidence and Findings

This section reports on the findings of the QCA analysis. The findings are presented according to the questions asked and by the themes and sub-themes identified. During the analysis the apriori themes from the Smart City dimensions (Table 1) were used to map relevant codes. Themes or sub-themes that had a negative connotation are written with an asterisk (*) in the bullet lists. In addition, some sample quotes are presented to illustrate the evidence.

4.1 Technological Value of Initiatives

The participants indicated the value of using technologies by answering the question "*What is the value of using the technologies and data sources?*"

The list of themes and sub-themes identified for value of using technology and data sources were:

- Smart Technology and ICT Infrastructure *(f = 13)*
  - Remote Access and Working (P7, P13, P14, P16, P18)
  - Access to Resources (Online Information) (P12, P13, P14, P15, P17)
  - Data Access (P7, P9)
  - Data Streaming (Dashboards, Decision-Making) (P8)
- Smart Living (*f = 10*)
  - Safety and Security (P13; P19, P21)
  - Convenience of Technologies (P13, P14, P16)
  - Education and Literacy (P13, P15)
  - *Corruption and Procurement (P21)
  - *Fake Qualifications and Skills (P21)
- Smart Environment (*f = 2*)
  - Sustainability (Resource Management) (P8, P11)
- Smart Economy (*f = 7*)
  - Paying Customers Quickly (P10)
  - Online Customer Service and Citizen Participation (P19)
  - Contribution to Smart Policy (P19)
  - Entrepreneurship (P12)
  - Efficient City (P21)
  - Mentoring (P10)
  - Time Saving (Marketing) and Business Development (Accelerated Products) (P10)

All of the themes could be linked to the four socio-technological dimensions of Smart Cities. Smart Technology and ICT Infrastructure was the theme with the highest frequency (*f* = 13). Smart Living had the second highest frequency (*f* = 10), which is interesting since the question was around technology and data, again highlighting the tight link between our social and technological worlds. The two sub-themes with the highest frequency counts (*f = 5*) were Remote Access and Working and Access to Resources (Online Information). Two negative sub-themes were Corruption and Procurement, and Fake Qualifications and Skills. Both of these negative sub-themes were identified by participant P21, who was a citizen of the Eastern Cape.

Regarding the value of technology, P10 said, "*A lot of this is all about time to market. You want it to get to market as quickly as possible even with our still state* *and our process is 3 years. . . . if you have the appropriate technology and the know-how and we bring in business savvy people around the mentoring so there's the whole human aspect around this as well. It obviously accelerated the whole process and that is really what you want to do. It's accelerated product development and about us getting to paying customers as quickly as possible.*"

P18 said: "*The main reason what we're trying to do is IT; we are aiming for return on investment. So the amount that we spent on this new technology with AI and IoT we have to reduce the cost like we're going to going to review our bring your own device policy. So then people are responsible for it and we can cut down on the cost and work more smartly.*"

4.2 Social Value of Initiatives

The social aspect includes the economy, the environment, and the social living attributes.

4.2.1 Smart Economy and Smart Environment

Two questions were asked regarding the "*Smart City initiatives' impact on the city's economy"* (E2.1) and the impact on the *"city's natural environment"* (E2.2).

The following themes and sub-themes were identified:

- Smart Environment ($f = 18$)
  - Resource Management (P7, P10, P11, P14, P18, P19, P20, P21, P22)
  - Navigation and Mobility (Reduced CO_2) (P11, P12, P13, P14, P17)
  - Awareness of Sustainability, e.g., Electric Vehicles (P7; P16)
  - Sustainability (Economy) (P11)
  - Economy and Service Delivery (P15)
- Smart Economy ($f = 12$)
  - Reduction of Costs (P8, P9, P11, P18, P22)
  - Attract Investors and New Markets (P13, P20, P21, P22)
  - Reduced Business Downtime (P19)
  - Service Delivery (Data Integrity) (P21)
  - Service Delivery (Navigation and Mobility) (P12)
- Smart Living ($f = 10$)
  - Employment and Skills Development (P8, P10, P14, P16, P17, P18, P20)
  - Improved Living Conditions (P19, P22)
  - Navigation and Mobility Convenience (P15)
- Smart Technology and ICT Infrastructure (f = 5)

– *Digitalization (IoT Readiness) and Connectivity (P8, P13, P14, P18, P21)

The theme Smart Environment had the highest frequency ($f = 18$), and Smart Economy ($f = 12$) had the second highest, which is to be expected since these were the themes of the questions. Some comments were made around the value of these initiatives for Smart Living. The comments regarding digitalization were negative, and participants reported on the lack of IoT readiness and connectivity in their cities. The sub-theme Resource Management had the highest number of related codes ($f = 9$), whilst Employment and Skills Development had the second highest ($f = 7$). In the previous Round 1 interviews, both Employment and Skills Development were also reported to have had an impact on the economy related to Smart City initiatives. In Round 2, this impact was again confirmed. For example, P17 indicated that *"upliftment"* was a factor that related to the community citizens finding themselves in a position to improve their education and seek better employment opportunities, thus contributing to positively impact the city's economy. Participant P20 also indicated that in their environment creating higher technology jobs will lead to *"higher-paid individuals"* and therefore *"it is an upliftment"* of the economy.

Regarding attracting investors and new markets, P20 said, "*…if we build this high tech environment, you know you start attracting other high tech companies."* Another participant (P21) had a similar comment and said that it *"…obviously deepens the impact in the value chain…greatly improved competitiveness… East London's a bit far away from markets and hasn't really got great logistics infrastructure…There's a lot of advantages that are going to come with the development of ICT and bringing all kinds of big digital players in."*

For Navigation and Mobility (Reduced CO_2), P14 said, *"…moving away from your paper based systems is good for the environment when you've got connectivity and access…not needing to move around so much, that's also going to reduce the carbon footprint."* Concerning Resource Management he said that *"You can access services from wherever you are, as long as you've have connectivity…the new residences have been built now are green buildings so they have been built with the environment in mind and connectivity in mind and safety, security, etc. So that's good for the environment for sure."*

Pertaining to Resource Management, P7 said, *"…when you use electric vehicles they are zero-emission vehicles, so they will contribute towards reducing the carbon footprint; and another aspect that some people also forget about is the uptake of electric vehicles also assist the overall health of the city in terms of reducing air pollution and air pollution also contributes to diseases such as like your asthma for example… noise reduction as well. Electric vehicles are much quieter."*

4.2.2 Smart Living (Social and Work Life)

The interview questions that are addressed in this section focus on the impact and value of the initiatives on the lives of the citizens in the Eastern Cape.

The following themes were identified, with related sub-themes:

- Smart Living ($f = 7$)
  - Reduce Stress (P7)
  - Smart Homes (P11)
  - Smart Work Life (P13)
  - Income and Sustainability (P15)
  - Fault Reporting (P19)
  - Data Access for Service Delivery (P20)
  - Education and Training to Uplift Communities (P17)
- Smart Technologies and ICT Infrastructure ($f = 6$)
  - Infrastructure e.g., wi-fi, roads (P18, P19; P21; P22)
  - Digitalization and IR4.0 (P8)
  - Vandalism (P19)
- Smart Economy ($f = 5$)
  - Process Improvement (P8, P14, P9)
  - *Smart Service Delivery (Lack of; Increased Costs) (P12, P21)
- Smart Environment ($f = 3$)
  - Awareness (P7, P11)
  - Sustainability—Recycling and Biogas (P10)

The theme with the highest frequency count was Smart Living ($f = 7$), which is to be expected since this was the theme of the question. What is interesting is that the theme that had the second highest frequency was that of Smart Technologies and ICT Infrastructure, again highlighting the close connection between social living and technology in today's world. The common sub-themes from Round 1 were Process Improvement and Sustainability. In Round 2, for example, P14 stated that less administration and improved workflow through automation made tasks easier.

Smart Service Delivery relates to those services associated with some digital activity or the use of smart technologies to deliver or access a service. Two participants highlighted negative impacts regarding Smart Service Delivery, one regarding the lack thereof (P12), and another (P21) stated that a lack of smart services has increased costs to citizens who receive inflated utility bills.

Concerning Living Conditions and Reducing Stress, P7 said, *"It makes life easier, like I would say, for example, driving an electric vehicle is easier than driving a petrol vehicle because you don't have to think about filling petrol everyday. You just charge the vehicle and also in terms of riding, an electric bike is actually less stressful in terms of peddling."*

For the theme Sustainability—Recycling and Biogas, P10 stated that *"…the Biodigester project we did was looking at selling gas in foil bags… we are looking at where we could provide that kind of a gas at a very low cost. It's very clean. Burning methane is, you know it's a bio gas. Yes, very environmentally friendly, but using waste, you know within the environment so you're cleaning up the environment in the townships, but you also providing very clean fuel."*

Regarding Education and Training, P17 said, *"There aren't actually very many places currently in the Nelson Mandela Bay area for second chance learners, they don't facilitate your training. They can work on their CVs, can upload it online, and email it out. They can do whatever research they need to on the laptop, so we've got all the tablets there with e-learning, and with having WiFi around town at various places it's just sort of uplifting everyone across the board."*

4.3 Value of the Initiatives

The participants were also asked to state what they believed were the direct benefits or value of their initiatives to the users or utilizers. The resulting themes were:

- Smart Technologies and ICT Infrastructure ($f = 9$)
  - Access to Resources (Online Information) (P12, P13, P20, P22)
  - Bridging the digital divide (P22)
  - Social Networking Platforms (P13)
  - Digitalization (P14, P21)
  - Collaborations (P15)
- Smart Living ($f = 9$)
  - Living Conditions (P14, P22)
  - Uplift Communities (P15, P17)
  - Knowledge (Acquisition, Sharing, Awareness) (P15, P16)
  - Training Center (Eco-Friendly) (P18)
  - Self-efficacy and Lifelong Learning (P16)
- Smart Economy ($f = 9$)
  - Cost Reduction (P7, P8, P9, P19, P20)
  - Job Creation (P10)
  - Return on Investment (P11)
  - Competitiveness (Foreign Investors) (P21)
  - *Productivity (P21)
  - *Service Delivery (Lack of/Inefficient) *(P21)*
- Smart Environment ($f = 3$)
  - Sustainability (Resource Management) (P10, P14, P15)

The themes with the highest frequency were Smart Technologies and ICT Infrastructure ($f = 9$) and Smart Living ($f = 9$). Regarding access to resources, P22 highlighted that Smart City initiatives have the potential to reduce the digital divide. The theme regarding Knowledge under Smart Living includes awareness, and participant P15 indicated that streets are dirty in townships (locations) and people are not willing to clean up. He explained that this related to not being as educated and aware of the benefits of being sustainable and the possibility of earning an income using waste as a resource of recycling. P16 explained the related impacts of their initiatives and their links to employee confidence and self-efficacy and lifelong learning. P21 said that productivity in the backward Buffalo City is declining and that service delivery is inefficient, whilst P22 said that their Smart City initiatives could help level the playing field by ensuring everybody receives the same service and access to information.

Cost Reduction had the highest frequency of sub-themes ($f = 5$) and was also mentioned in Round 1, as well as being mentioned in earlier interview questions. Regarding this theme, P9 said, *"We think that using our software you can actually reduce entire plant floor factory costs. You can save a lot of your time and then you can improve your overall plant efficiency.*" Sustainability (Resource Management) was also mentioned in the discussion of the previous questions.

4.4 Gaps in Benefits and Value of the Initiatives

The participants were also asked if they thought the benefits of initiatives were as they expected, and to identify gaps between their initiatives' expected and actual benefits. One participant, P16, had a mixed response and indicated "*No*" from a short-term viewpoint based on the perspective of the employer of his customers who are the employees, but "*Yes"* from the perspective of the employee gaining immediate benefits. Four participants (P17, P18, P19, P22) said that generally expectations had been met for them, whilst five participants (P8, P13, P14, P20, P21) said that Smart City initiatives in their city were still in the early stages and that progress was slow. For example, P21 said, "*...there are some efforts underway in Buffalo City in the Metro and they not being integrated in a kind of Smart City strategy...they are still very silo-based... one department will put up cameras from a public safety perspective, but they not necessarily linked to, you know South African Police or private security, and so there's a lot of issues around lack of data integration. You really need a Smart City strategy that can provide that level of integration...it's all about integration, data sharing, open platforms and things, and I think that's what we have to shift the city towards...*". Two participants indicated that even though their Smart City initiatives are in the early stages they are reaping some benefits.

The main gaps reported were the problems with infrastructure, specifically the lack of Internet or WiFi connectivity, and the awareness and learning curve for technology and smart devices. Learning these new technologies also takes a lot of time. The increased physical divide was highlighted by three participants (P13, P15, P22) as a major challenge for Smart City initiatives. One participant (P17) highlighted the struggle of sustainability of resources and of keeping initiatives sustainable, and said that "*...the problem now that we face is we got a decent amount of funding and it was able to take us to this particular level...it was a positive gap in terms of what we're expecting and what we did deliver in terms of an impact...But* *now our contract for the WiFi will end…so it now becomes difficult problem. The problem we're facing now is how do we get the next round of funding?…How do we make the WiFi sustainable?...from a consistent WiFi usage, it's not sustainable…"*.

P12 was quite convinced that there was a large gap between expectations and what value was experienced, specifically for the smart service delivery theme and government's failure to deliver. He stated that "…*Yeah there is a gap. A huge gap, you know, the stuff that they promised. They don't deliver. And I mean I can appreciate their attempt, but I mean they are the government. So you know I can't expect less from them. I must expect more…*".

5 Claims: Discussion and Recommendations

Based on the top themes from the QCA of the interviews, several factors that influence the socio-technological (Technological and Social—Economic, Social and Environmental) value of Smart City initiatives were identified. Figure 2 presents the network diagram of these factors. From these findings, the recommendations are that these newly identified factors should be added to the initial list of factors in Table 1. Table 3 summarizes the comprehensive list of recommended success factors for Socio-technological value of Smart City initiatives.

Many of the success factors identified in literature were repeated in the interviews. For example, Sustainability (Resource Management) and Infrastructure, e.g., WiFi and roads, were both top themes and have already been deemed important for Smart City initiatives in other studies, so they do not need to be re-added. The interview findings did, however, reveal some new and interesting factors that were not listed in Table 1. For the technological aspect, digitalization and IoT readiness, as well as connectivity to online resources were highlighted as key factors. For Smart Living, three new factors were emphasized.

Safety and security are important issues in developing countries like South Africa, where crime and corruption levels are high. The convenience of technologies and how they can provide value to citizens were also mentioned, and so Smart City initiatives can introduce this convenience. Lastly, the potential value of these initiatives to develop skills and improve education was thought to be an important factor. In terms of the environment, navigation and mobility was considered as a key factor that can improve the value of citizens' lives, since it reduces the carbon dioxide levels and ultimately reduces the negative impact on the environment. Three new factors for the Smart Economy dimension were identified, namely the reduction of costs, the opportunities of new markets and investors, and the improvements for processes that new technologies in Smart Cities provide.

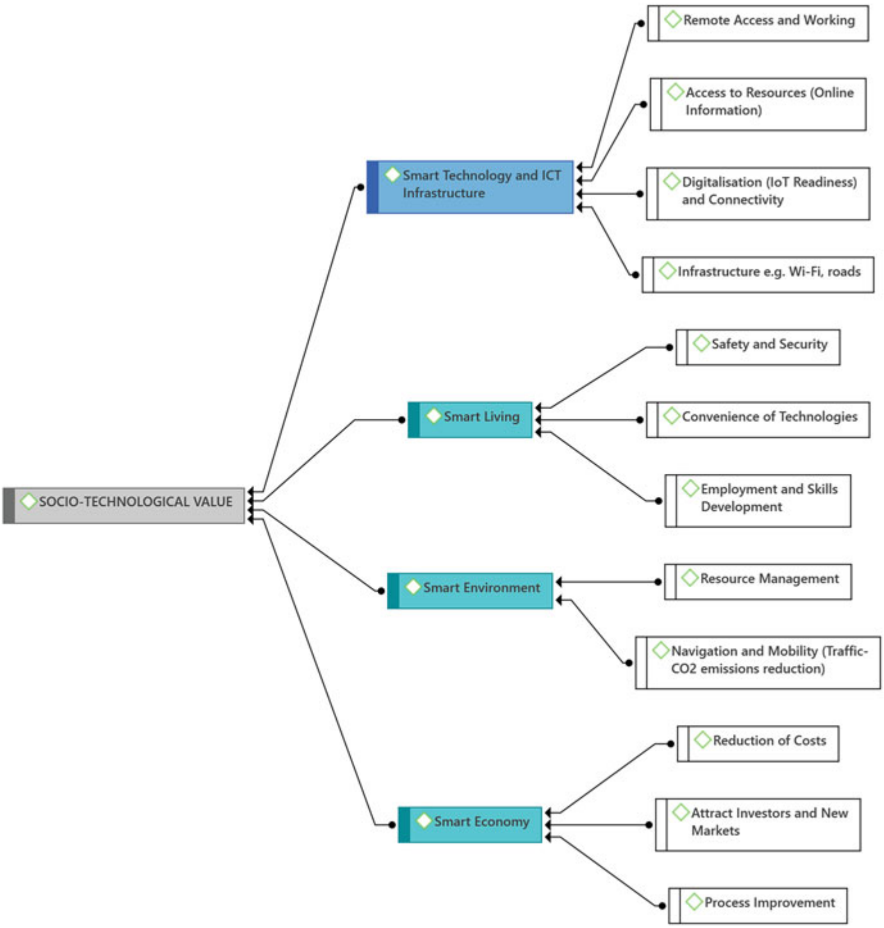

Fig. 2 Factors of socio-technological value for Smart City initiatives

6 Conclusions and Future Research

This chapter addressed the socio-technological value of Smart City initiatives and proposes factors that can be used as measures for evaluating this value in Smart City projects and initiatives. The socio- and technological-value to stakeholders (Table 3) were identified for Smart City initiatives to address urbanization challenges. The research was undergirded by theory and verified by interviews with Smart City stakeholders in two case studies in the Eastern Cape province of South Africa. The participants confirmed the factors identified from literature and also raised other factors, issues and concerns not previously identified in related research. The dimensions of Smart Cities and the socio-technological perspective were

Table 3 Comprehensive set of success factors for socio-technological value of Smart City initiatives

Social value		
Smart economy: • Economic image and trademarks • Entrepreneurship • Flexibility of labor market • Innovative spirit • International embeddedness • Productivity • ***Attract investors and new markets*** • ***Reduction of costs*** • ***Service delivery***	**Smart environment:** • Attractiveness of natural conditions • Environmental protection • Future proof • Pollution • Sustainable resource management • ***Awareness of sustainability, e.g., Electric Vehicles*** • ***Navigation and mobility (reduced CO_2)***	**Smart living:** • Cultural facilities • Health conditions • Individual safety • Housing quality • Education facilities • Touristic attractiveness (smart tourism) • Social cohesion • ***Improved living conditions*** • ***Safety and security*** • ***Employment and skills development*** • ***Convenience of technologies***
Technological value		
Smart technology and ICT infrastructure: • Smart technologies • Smart data • Availability of ICT infrastructure • ***Access to resources (online) and working*** • ***Digitalization (IoT readiness) and connectivity***		

successfully used to classify the factors highlighted in the interviews. The set of factors can be useful to stakeholders of Smart Cities, who can use them to plan and evaluate Smart City projects. For researchers, the gaps in literature have been filled by the findings to some extent. The limitation of the study is that it was only conducted in two case studies with 16 participant interviews. However, the findings can still provide useful insight into the status of Smart City projects in developing countries. Future research should apply these factors to other cases in developing countries where Smart City initiatives are conducted.

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Appendix: QCA Steps Followed

The QCA steps followed in this chapter were as follows:

Step 1: Deciding on a research question—This step involved the contextualization of the research question as part FraIM (Fig. 1).

Step 2: Selecting material—Use of transcribed data from the interviews.

Step 3: Building a coding frame—The tasks followed were:

- Selecting material (i.e., transcriptions)
- Structuring and generating categories or themes
- Defining themes (main and sub-themes)
- Revising and expanding the frame (until saturation is reached)

Saturation is described by Schreier (2013) as the point at which no additional or new themes can be found and is an important concept in collecting and analyzing qualitative/narrative data. Data saturation was reached when participants provided similar responses to questions and new themes could not be identified. Excel and Atlas.ti software were used to assist with these tasks.

Step 4: Segmentation—The transcriptions were divided into units (i.e., interview questions) so that each unit fits into exactly one theme of the coding frame. Dividing the transcriptions into themes requires formal (words, sentences, or paragraphs in the text) and thematic (changes in topic) criteria.

Step 5: Trial coding—An example of how the coding process was applied is: a unit was entered into a row, a main category/theme was the column, and the cell data was the formal and thematic criteria (sentences and quotes from the transcriptions).

Step 6: Evaluating and modifying the coding frame—The evaluation of codes involved the examination (by coders that were not the researcher) of the trial code sheet results to ensure validity and reliability. This examination included assigning units of coding to both coding rounds. Higher consistency between the rounds resulted in a higher quality coding frame.

Step 7: Main analysis—All transcriptions were analyzed to answer the research question.

Step 8: Presentation and interpretation of evidence—The coding frame, sample quotes and analysis of themes are presented in this chapter.

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Part IV
Data Analytics for Sustainability

Development of a Quantitative Validation of Valuation Methods for Power Plants and Energy Systems Using a Simulation-Based Benchmark

Steffen Wehkamp, Fernando Andres Penaherrera Vaca, and Jorge Marx Gómez

Abstract Changing framework conditions requires adapting financial valuation methods for power plants and energy systems. Up to now newly developed or adapted valuation methods have been validated qualitatively, based on expert statements. This paper presents a structured development process for quantitative validation of valuation methods.

The Xerox method for developing a benchmark is used to develop key figures that verify the plausibility of the simplified Valuation Methods. The method for developing a simulation study is used to analyze the requirements of a simulation model whose results can serve as reference values for benchmarking. To support the plausibility of the approach, structured methods were used to create both the benchmark and the simulation model.

The process results in the development of a framework that serves as a baseline to perform a benchmark of the different methods. These provide indicators that analyze quantitatively the validity of the valuation methods. Existing simulation models for complex energy systems need to be adapted to provide the required reference values. This needs modification of these models, based on the requirements of the valuation methods. The results provide then a novel approach to the evaluation of these valuation methods.

Keywords Energy system investment · Valuation method · Quantitative evaluation · Flexibility

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Abbreviations

CBC	COIN-OR branch-and-cut
DCF	Discounted-cash-flow
EEX	European energy exchange
ENaQ	Energetisches Nachbarschaftsquartier Fliegerhorst Oldenburg
KPI	Key-performance-indicators
LFM	Local flexibility market
LHV	Lower heating value
oemof	Open energy modelling framework
OTC	Over-the-counter
PV	Photovoltaic
RO	Real option
SPM	Simulation procedure model
STC	Standard test conditions
WT	Wind turbine

1 Introduction

Prior to investment decisions, valuation methods are often used to provide investors with financial information about the investment. These methods include expected cash flows and key figures for comparing investment options. Since the objects of valuation can be very different, adapted valuation methods were developed for this purpose.

Historically, national European energy supply systems are often based on centralized large-scale power plants. The energy system was financed through corporate investments. To hedge these investments, energy exchanges offered future products, on which energy could be traded up to 4 years before the delivery date. This allowed future cash flows to be guaranteed to shareholders for 4 years after completion of the power plant. Based on this pragmatic assumption, the financial values were determined through future markets. The growth of renewable energies, the increasing decentralization of supply, and the resulting need for flexibility represent new requirements for the energy system. As a result of this change, new market requirements were identified, reflecting the need for adapted valuation methods. This need was taken up in research and new methods were developed (Kozlova, 2017). These valuation methods are often applied to common power plant technologies to prove and demonstrate their functionality. In the existing literature, new methods are considered to be of better quality if the valuation methods take these new requirements into account (e.g., Kryzia et al. (2020), Mancini et al. (2016), Martinez-Cesea and Mutale (2011), Weibel and Madlener (2015)). There is currently a lack of a methodology that can quantitatively analyze and plausibly compare these valuation methods. The research gap in quantitative validation of valuation methods for investments in energy plants was presented by (Wehkamp et al., 2020).

This paper presents the development of a method for evaluation and validation of different valuation methods applied to power plants and energy systems. Section 2 details the theoretical background on valuation methods, on the used benchmark method, and the used simulation method. Section 3 outlines the proposed procedure of the benchmark applied specifically to this valuation and details the requirements of a model. To create a new validation method for valuation methods, we created a benchmark. We used an existing benchmark creation method, presented in Sect. 2, to have a validated methodological foundation. Within this benchmark, the valuation results are compared with reference values. We used an existing simulation creation method, presented in Sect. 2, to have a validated methodological foundation. Within this simulation, the reference values for the benchmark are calculated. Section 4 specifies the changes required for an already developed model to adapt it for a valuation benchmark. Future work required to provide a baseline for validation of valuation methods is described in detail. Section 5 summarizes the findings and provides conclusions and perspectives on future work on the model and the benchmarking process.

2 Theoretical Background

This chapter illustrates the approaches used to develop a quantitative validation of valuation methods for different investments in energy plants. The basics of the different valuation methods are first presented. There is no direct comparison of the valuation methods. Otherwise, there is a risk that inadequate (or adequate) methods will be compared with each other. This would not allow any conclusions to be drawn about the general quality or the actual performance. The comparison should contain reference values that have been developed independently of the valuation methods. This comparison is performed in the context of a benchmark. This benchmark includes the comparison of the results with reference values. The aim is then to create a simulation model that represents the environment of energy systems to determine the above-mentioned reference values. The structure of this approach is shown in Fig. 1.

To support the validity of the benchmark and the simulation, already existing procedures for benchmarking and for conducting a simulation study were applied. These are presented following the valuation methods.

2.1 Valuation Method

The most common valuation methods in research and practice are the so-called Relative Valuation method, Discounted-Cash-Flow (DCF) method and Contingent

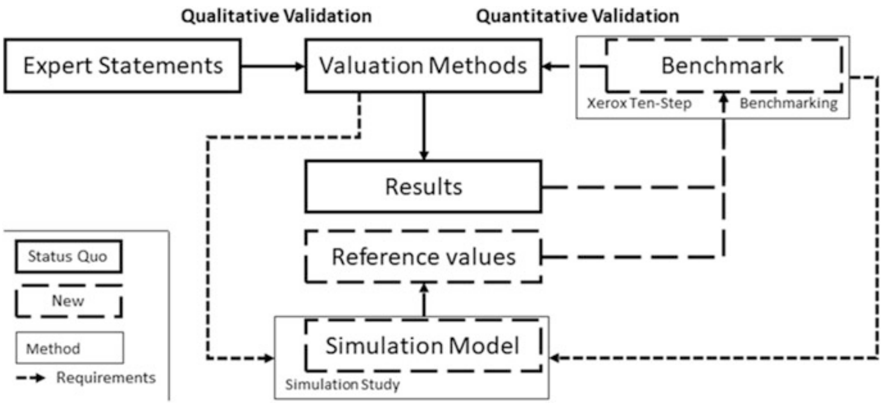

Fig. 1 Methodological structure to validate valuation methods

Claim Valuation method (Damodaran, 2012). The Relative Valuation method is commonly used for publicly listed companies and not applied to power plants. The DCF method is the status quo within practice. Within the Contingent Claim Valuation, the Real Option (RO) approach is commonly used with a power plant as the valuation object (Hsu, 1998; Frayer & Uludere, 2001; Fernandes et al., 2011; Chang, 2013; Martínez Ceseña et al., 2013; Kim et al., 2017; Kozlova, 2017). This paper, therefore, focuses on the DCF and Real Options methods.

2.1.1 Classic Discounted-Cash-Flow

The DCF method is based on the present value rule. The present value rule states that the value of an asset is the present value of all expected future cash flows CF (Damodaran, 2012). These expected cash flows are discounted to the valuation date using the discount rate r for the life span n for each period t. The discount rate r is determined depending on the risk of an investment.

$$\text{Value} = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} \tag{1}$$

The traditional markets for selling energy were the futures markets and bilateral agreements (so-called Over-the-Counter, OTC) contracts. The most-traded products here are the Future Base and Future Peak. Future base is a band production of energy for a complete year. In this product, the offered service must be produced continuously (24/7) for the entire duration. The Future peak product is for the times of peak load between 8 h:00 and 20 h:00 for weekdays for the entire duration. This valuation method uses these prices as a foundation to calculate the future cash flows to determine the present value. Two relevant assumptions are made here: (1) The value of capacity within the peak block is measured with the peak price. Outside the peak product, the base price is used as the basis for valuation. Thus, the physical delivery liabilities of the base product are neglected for the peak time. (2) With flexible production, different capacities can be offered within the times of the base as well as the peak product. Thus, the delivery liability of uniform power output for a product is neglected.

Earnings E are then calculated according to the product price p times the traded quantity x.

$$E = p \times x \tag{2}$$

On the other hand, the cash flows of the costs C must be considered. The costs C are the sum of fixed costs CF and variable costs CV. The fixed costs CF are the depreciation of the investment and generation-independent costs. Variable costs CV are the product of specific variable costs c_V and production volume x. In the case of power plants, specific variable costs c_V are typically defined as the sum of the cost of fuel c_{vF}, the cost for CO_2 emissions c_{CO2} and the cost of operation and maintenance $c_{\mathrm{O\&M}}$.

$$C = C_F + C_V \tag{3}$$

$$C_V = c_V \times x \tag{4}$$

$$c_V = c_{vF} + c_{\mathrm{CO2}} + c_{\mathrm{O\&M}} \tag{5}$$

The variable cost of electrical energy for fuel c_{vF} is equal to the fuel cost of thermal energy c_F divided by the efficiency η.

$$c_{vF} = \frac{c_F}{\eta} \tag{6}$$

The cost for CO_2 emissions c_{CO2} is the ratio of the emission factor EF of the respective fuel and the efficiency η multiplied by the costs for CO_2 certificates c_{cert}.

$$c_{\mathrm{CO2}} = \frac{EF}{\eta} \times c_{\mathrm{cert}} \tag{7}$$

The delivered energy price then needs to exceed the variable cost to be profitable. The sum of the profits at times when the electricity prices are above the variable costs are the expected cash flows. These are added up to 1 year and discounted to the valuation date. The sum of the discounted annual profits results in the value of the investment.

2.1.2 Modern Discounted-Cash-Flow

The DCF approach newly presented by Wehkamp et al. (2021) allows different markets to be considered for the expected future cash flows. For the forecast of the energy exchange markets, the modern DCF method uses a statistical analysis of historical market data. The future market and the spot market products are considered. Daily price patterns are used for expected future cash flows. Historical market data was examined to determine which parameters can be used to predict prices. For this purpose, the average hourly and quarter-hourly prices are assessed, depending on the days of the week and month. The basis of the price pattern included values for all hours (day-ahead) or quarter-hours (intraday) of a day of a month. In this way, simplified price patterns are created initially. E.g., the price for the quarter-hour product from 13:30 to 13:45 in February on Tuesdays is 23.84 €/MWh. Since short-term trading takes place on the spot markets, the valuation and hedging character of the classic DCF method are not given here.

This approach includes further marketing options by considering the day-ahead and intraday markets. In contrast to the classical DCF-procedure, there is a differentiation between the prices of the marketing options p_{MO}.

$$E - C_V = p_{\mathrm{MO}} \times x - \left(\frac{c_F}{\eta} + \frac{EF}{\eta} \times c_{\mathrm{cert}} + c_{\mathrm{O\&M}} \right) \times x \tag{8}$$

The spot market is especially relevant for flexible and volatile power plants and virtual power plants. The typical course of the respective markets is represented by the statistical procedure. However, it is critical to see that the price peaks outside the average daily course were removed. Especially in the case of storage technologies, that use these peaks, it is likely that these will also be undervalued. This is also the case of the classical DCF method. Thus, this approach also limits the valuation of flexibility.

2.1.3 Real Option

The latest accepted method in the field of valuation is the RO method. In this method, it is assumed that the value of investment consists not only of the expected future cash flows but also of the value of the flexibility. Flexibility in this paper means the ability to adapt to current market events. This ability can be given, for example, if it is possible to deviate positively or negatively from a scheduled production to balance out bottlenecks in the grid. In this context, it is expected that the flexibility of power plants can be used profitably on volatile markets. The more volatile the market, the greater the value of flexibility. With the classic DCF method, these flexibilities have the opposite effect on the value of the investment. The volatility of the market is used in the risk interest rate for discounting the cash flows. The higher the volatility, and therefore, the uncertainty of the market, the lower the value of an investment. Thus, there are fundamentally different assumptions in the approaches here.

This method is based on the Black-and-Scholes formula for valuing financial options (Black & Scholes, 1973). Financial options are stock exchange products in which the right to buy or sell is acquired for a later date at a certain price. Copeland (2001) defined Real Options *"as the right, but not the obligation, to take an action (e.g., deferring, expanding, contracting or abandoning) at a predetermined cost, called exercise price, for a predetermined period of time – the life of the option."* It is possible to transfer financial options methodology to power plants by considering the production of power plants as a series of call options (Hsu, 1998).

By investing in a power plant, the operator has the option to offer the capacity of the power plant for 8.760 h on the day-ahead market or 35.040 quarter-hours on the intraday market. The value of each of these options must be determined.[1] In combination with the DCF method, an option value OV is added to the expected value of the produced kWh, which can be achieved under certain market conditions.

$$E = p \times (x + OV) \tag{9}$$

This approach is criticized in that when Option Theory is applied, expertise is often missing and used in inappropriate contexts (Godinho, 2006; Schachter & Mancarella, 2016).

2.2 Benchmark

The methods presented are applied when valuating a power supply plant. Since no quantitative evaluation exists so far, no quantitative conclusions can be drawn by comparing the results. To compare the results of the valuation methods with reference values, we have developed a benchmark. The applied method was initially presented by Camp (1989) and is called Xerox 10-step benchmarking process. This approach was chosen due to its generic nature and broad acceptance (Anand & Kodali, 2008; Partovi, 1994). In the following section, the 10 steps of this benchmarking method are briefly explained. The application of the process is described in Sect. 3.

Step 1—Identify the Benchmarking Subject: In this step, it should be determined what the goal of the benchmark is and. Deriving from this, what will be benchmarked. According to Partovi (1994), this is the most important step of the benchmark. Special focus should be put on this step because an adjustment of the results can mean in the worst case a repetition of all following steps.

Step 2—Identify the Benchmarking Partners: Typically, this step is used to identify products or processes that are like one's own and with which one competes.

[1] For leap years: 8.784 h on the day-ahead market or 35.136 quarter-hours on the intraday market.

The task here is to select best-practice examples to do justice to the guiding character of the benchmark. The relevant institutions should be willing to participate in a benchmark if the necessary data cannot be obtained otherwise.

Step 3—Determine Data Collection Method and Collect Data: This step includes the structured process of data collection. To reduce unnecessary effort, the initial focus should be on the selection of data to be collected. A wrong design in Step 1 can mean a significant additional effort.

Step 4—Determine Current Competitive Gap: In this step, gaps in existing performance are to be uncovered, which are necessary to achieve the objectives. This gap corresponds to new requirements, which often arise due to changed framework conditions. In this step, existing best-practice examples are often used to identify quality criteria. However, it is also possible to derive further quality criteria based on criticism of existing solutions.

Step 5—Project Future Performance: The initial task is to develop forecasts of future performance trends in the context of the benchmark. Based on these forecasts, possible courses of action are to be determined to adjust one's performance in the direction of the targets. This will enable executives to make well-founded decisions regarding activities to improve their own performance.

Step 6—Communicate Findings and Gain Acceptance: The results of the benchmark must be communicated in a way that the adjustment benefits are necessary. The aim is to motivate people to contribute to these adjustments.

Step 7—Establish Functional Goals: Goals are formulated which are necessary to achieve the goals of Step 1. These are necessary to close the existing performance gap. These goals can be created according to the SMART principle (Drucker, 1995). These can therefore be intermediate goals. Here, the goals must be created in consensus with the stakeholders and are attractive to those involved. This requires reference values, which have already been validated.

Step 8—Develop Action Plan: A plan is derived from the objectives of Steps 1 and 7. First, necessary individual activities are collected. The implementation of these activities must be set up in a logical sequence. This step also serves to assure the benchmark team towards the executives. For this purpose, the activities are again reconciled, and the necessary support is then requested.

Step 9—Implement Plans and Monitor Progress: The defined measures from step 8 are implemented in this step. Additionally, a regular monitoring process is introduced. Over time, this serves to determine the extent to which the formulated objectives have been achieved. This enables to react to deviations from the plan.

Step 10—Recalibrate the benchmark: This step is used to critically review the benchmark process. Missing, wrong, too high or too low goals can be identified. This is to ensure that the goals set are up to date with the existing best-practice performance. Furthermore, decisions from the previous steps can be reviewed in a structured way. This offers the possibility to readjust them.

2.3 Simulation

The benchmarking process defines functional targets (Step 7). A simulation study allows then obtaining reference values for the functional target. For power plants, this simulation provides information on energy flows and their costs with sufficient resolution to consider the flexibility of the energy systems. A systematic approach to create the simulation ensures that these reference values are valid.

Simulation has become a major source of knowledge. It is applied in many scientific disciplines and economic sectors for advancing research and for supporting decisions as it provides efficient, economic, and convenient approaches for analyzing complex systems, such as energy systems (Chan et al., 2017; Tolk et al., 2013).

2.3.1 Introduction to Simulation

A simulation study is a project that uses simulations to answer research questions about a system. These inferential processes investigate complex phenomena utilizing computational techniques. Simulation studies consist of two parts: the conception and implementation of the simulation model (modeling) and the design, execution, and evaluation of simulation experiments (experimentation) (Chan et al., 2017; Law & Kelton, 2000). To achieve the objective of a simulation study and to address specific research questions (Maria, 1997), corresponding performance indicators are specified. Simulation experiments are conducted to analyze and compare the influence that different parametrizations of the model have on the values of these indicators. Thus gaining a better understanding of the model and the system it represents (Hill, 2002).

Experimentation with constructed models allows exploring the behavior of the described systems (Gutenschwager et al., 2017). These experiments often consist of parameter variations or replications. Each experiment describes a series of tests with changes to the inputs (Montgomery et al., 2012; Wilsdorf et al., 2019). A simulation study consists of at least one simulation experiment per question regarding the system. For each simulation experiment, of one or many simulation scenarios runs to monitor the response of the system to a specific set of inputs.

The inner structure of the model determines the behavior of the modelled system. However, often the structure is neither accessible nor essential for assessing this behavior. In a black-box approach, the experimentation only relies on the observable behavior of the model (Chan et al., 2017).

2.3.2 Simulation Procedure

The Simulation Procedure defines the different steps in a simulation study. A Simulation Procedure Model describes the path from the object specification of a concept and implementation of the model with a simulation tool to the generation of

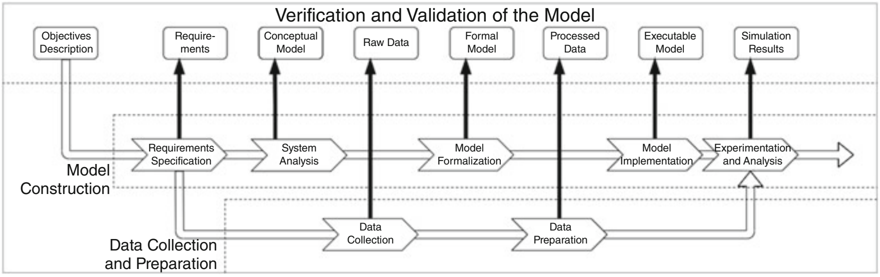

Fig. 2 Simulation Procedure Modell. Adapted from Gutenschwager et al. (2017)

results. There are several procedures, with different degrees of complexity**.** Figure 2 describes the procedure developed by Gutenschwager et al. (2017). The different steps in a Simulation Study are:

(a) **Objectives Description:**

- **Goal Specification:** Describes the goals of the project and the problem and provides a justification for the use of a simulation as a problem-solving method.
- **Task Definition:** Develops specific objectives and competences of the target description. The documentation of "Tasks Specifications" details the different responsibilities of the project stakeholders.

(b) **Model Construction:**

- **Systems Analysis:** Defines the model properties such as detail degree and system boundaries. Defines elements to be modelled, with which accuracy, and how they interrelate. A resulting "Conceptual Model" represents the considered elements and their relations. This shall include the system boundaries, elements, and their accuracy of these. Two design approaches exist: Top-down, which breaks down a system is broken into its further components; and Bottom-up, which builds a model based on behaviors and events.
- **Model Formalization:** Transfers the concept model in the formal model. The formal model sets the structural procedure for the computational model, such as in flow charts. This represents the component dependencies. The formalization corresponds to the model specification in the software development process. Thus, a mathematical representation of the dependencies and relations of the different elements is required. Pseudo-code or algorithmic descriptions of software represent the components.
- **Implementation of the Executable Model:** Refers to the creation and execution of the computational model based on the conceptual model and the simulation tool. This requires the input of the model description and its transformation in to in a programming language or a tool-specific scripting language.

(c) **Data Collection and Preparation**

- **Data Collection:** Encompasses the compilation or generation of necessary data for the simulation study as raw data. The required information comes from the Tasks Specifications and the conceptual model.
- **Data Processing:** Refers to the processing of raw data to be usable by the executable model. Typical processing tasks are restructuring, filtering, filling gaps, formatting, or statistical analysis. This results in data available for the executable model and thus for the experimental procedure.

(d) **Experiments and Analysis:**

- **Experimentation:** Utilizes the executable model and the processed data for the calculation of output results. The initial “Objectives Description Statements” formulates the expected results and thus the initial designs on experiments. An “Experiment Plan” is required to correspond the results with the project objectives. The Experiment Plans detail the conduction of simulation experiments based on the research questions and on the different parameters.
- **Analysis:** Evaluate the outputs of the experimentation according to the research questions. This allows delivering conclusions to the real system. The simulation results overall include both the conclusions and the underlying recorded data and their analysis.

(e) **Verification and Validation:** Verification and validation in data and models through the whole simulation study reduce the risk of errors and increase result quality. To verify the simulation results, several tests such as dimension test, fixed values test, sensitivity analysis, and comparison with other models are applicable methods (Rabe et al., 2008).

2.3.3 Experiment Planning and Execution

This subsection describes all tasks incurred during a simulation study for the planning and execution of experiments. The “Objectives Description” documentation includes statements on the expected results and also initial considerations on required experiments (Gutenschwager et al., 2017). Relevant experiments and respective experiment hypotheses are derived from the goals of the study and the observed behavior of the model provides evidence whether these hypotheses hold (Chan et al., 2017).

(a) **Experiment Plan:** Contemplates the required structural and parametrical changes to the model. Replication experiments can modify the initial values and keep the operational parameters (Rabe et al., 2008), and are the basis for statistical validations. Replication studies also consider several iterations of the same simulation run with the same parameters for stability analysis. Parameters (or factors) can be qualitative and quantitative. Market strategies, such as day-ahead market or intra-day market, are examples of qualitative factors. Quantitative factors are, for example, the installed power of a photovoltaic plant.

(b) **Development of the Experiment:** The Experiment Plan contemplates what parameters should be modified. Several types of analyses are possible:

- What-if-Analysis: Evaluates different parameter combinations, and how these variations influence the resulting indicators. This can allow ranking and selection of different alternatives.
- How-to-achieve-Analysis: This has as goal to find a parameter configuration to reach pre-defined target variables or optimal solutions. The amount of simulation runs is firstly unknown. Parameter selection is configured through learning and optimization algorithms.
- Statistical Methods: Uses methods such as replications, batch means, regenerative, and others to perform statistical analysis of simulation output data. Variance reduction techniques can be implemented to obtain greater statistical accuracy for the same amount of simulation runs (Balci, 2012).

(c) **Experimentation Execution:** The end of the experimentation is to obtain the results of all the parameter configurations or to find the optimal results of a dynamic parameter configuration. Unobtainable solutions are also possible. In this case, an identification of causes and definition of gaps to close is required. This can lead to structural changes in the model, such as the implementation of additional variables, the requirement of additional data, or changes in the structure of the model (Gutenschwager et al., 2017). This results in a new experiment plan, requiring an iterative approach until obtainment of the objectives. This also requires a specification of the length of the overall study and the number of runs for each scenario. Simulation study is a lengthy process and requires definition of time limits to accomplish goals on time (Banks, 1998).

3 Methodology

To validate the results of the valuation methods, a benchmark is performed, which quantifies the quality of the valuation methods. Within this benchmark, key figures are developed that verify the realism of the simplified Valuation Methods. Figure 1 already shows that the valuation methods and the benchmark create requirements for the simulation. This is because the valuation methods and the simulation should be based as far as possible on a uniform data basis and methodical calculation of the cash flows. Since specific goals are still being developed in the benchmark process, requirements for the simulation can also be derived from these. Therefore, the benchmark process will be presented first and then the simulation process will be explained.

The development of the validation tool consists of the establishment of a benchmark and of the creation of a simulation model that provides the reference values for the benchmark.

3.1 Benchmark Procedure

In the following, the already executed and planned steps of the benchmark process are explained. Due to the generic nature of the "Xerox ten-step method," it was possible to adapt the steps to this use case.

Step 1—Identify the Benchmarking Subject: The goal of presented valuation methods is to reflect the economic performance of power plants and energy systems. The aim is to obtain the most accurate result possible with a reasonable amount of effort. The aim of this benchmark is therefore to determine to what extent the simplified valuation method can represent the actual performance. The extension of the DCF method, which is being developed in the context of this paper, should be improved by this benchmark.

Step 2—Identify Benchmarking Partners: In this case, the focus lies on the different methods that economically value power plants and energy systems. This has already been determined in a preliminary study (Wehkamp et al., 2021). To consider the views of different stakeholders, a benchmark team was formed, consisting of people from different institutions in science and industry. The researchers work in the fields of computer science, energy economics, energy technology, and thermodynamics. The industry partners work in the fields of power plant operation, energy consulting and management, grid operation, energy sales and plant manufacturers.

Step 3—Determine Data Collection Method and Collect Data: It was assumed that the data inputs and outputs of the model must correspond to those of the valuation procedure so that comparison is feasible. To properly use the results of the simulation as reference values in a benchmark, the simulation must comply with data requirements from the valuation methods. In line with the objective of the benchmark, indicators were developed in a workshop with the benchmark team. These indicators are intended to measure the described goal: determination quality of the economic performance of valuation methods.

Step 4—Determine Current Competitive Gap: Wehkamp et al. (2021) determined the current competitive gap in a preliminary study by comparing different valuation methods. The literature was selected on basis of 5 literature reviews (Martínez Ceseña et al., 2013; Chang, 2013; Fernandes et al., 2011; Kim et al., 2017; Kozlova, 2017). In addition, the respective criticism in literature to the valuation methods was considered (Frayer & Uludere, 2001; Godinho, 2006; Schachter & Mancarella, 2016). This was summarized in a catalog of requirements. It was found that the practical relevance, the volatility of the electricity markets, and the flexibility of power plants are overlooked in the valuation methods.

Step 5—Project Future Performance: At this stage of the benchmark, no forecasts are made. As there is a gap between the state of the art in practice and science, this step is characterized by uncertainty. As this benchmark is the very first to quantitatively evaluate the results of valuation methods for power plants and energy systems, it can be an important step to initiate change in this field.

Step 6—Communicate Findings and Gain Acceptance: The status of the study and thus of the benchmark will be communicated through this and future papers. The discourse with the benchmark team, editors, reviewers, and the readers of this journal are considered a relevant part of this step. The communicability of the benchmark in the field of practice was set as an important requirement. Thus, the critique from Step 4 is taken up and the practical relevance is supported.

Step 7—Establish Functional Goals: The functional goals were derived based on the valuation methods and an expert interview. These include reference values for the benchmark as well as functions for the model itself.

(a) **Requirements from Valuation Methods:** On the revenue side, the exchange prices for electricity are considered in the valuation of power plants. Historical prices for electricity on the future, day-ahead and intra-day are used as the basis for valuation.

The techno-economic parameters considered are level of efficiency [%], specific investment cost [€/kW], operation and maintenance cost [€/a and €/kWh], fuel cost [€/kWh], emission factor [t/kWh], CO2-certifice price [€/t] and the discount rate [%].

(b) **Requirements from Expert Workshop:** The economic metrics of the valuation are incorporated into the benchmark. These include earnings, costs (variable & fixed), revenue and capital costs. In addition to the results of a valuation, the Key-Performance-Indicators (KPI) developed in the benchmark will be calculated. A workshop was held to define KPI that determine the adequacy of the valuation methods used to determine economic performance. For this purpose, the basic application and context of valuation methods were explained. This workshop was attended by 12 participants. The result of the first part of the workshop resulted in the following KPI:

1. Revenues generated on the respective markets
2. Full load hours
3. Correlation coefficient of the cash flow sequences of the respective markets

KPI 1 is to be calculated to determine whether different marketing options are adequately considered in the valuation methods. This indicator focuses on the significance of the revenues and differentiates them for the various marketing options. The second KPI is intended to allow conclusions to be drawn as to how many hours per year the invested capital was used productively. The third KPI is intended to provide further information on whether the assumptions of the valuation methods are also appropriate over time to reflect the market. In the further course of the benchmark process, it will be reviewed whether adjustments or additions to the indicators are necessary. The second part of the workshop was focused on the model itself. Here, points were worked out which the model should be able to represent in principle.

- Residual load capability
- Consideration of uncertain parameters: regulatory, economic environment (e.g., CO_2 certificates, promotion of renewable energies)

- Consideration of the development of specific investment costs
- Reaction times of power plants
- Internalization of external costs
- Reputation gain/loss of companies through technology selection
- Offering flexibility, e.g., via German control power markets
- Lifetime and degradation of power over time
- Extensibility for further marketing options

Step 8—Develop Action Plan: In addition to Step 6, the aim is to further develop the benchmark, the simulation and the adaptation of existing evaluation methods in an exchange with practitioners. This will be part of future work and is part of this application strategy.

Step 9—Implement Plans and Monitor Progress: Step 9 has yet to be executed. The assessment of the proposed framework will be taken up through a case study.

Step 10—Recalibrate the Benchmark: Further studies can be carried out to improve the proposed model and new practices, which may evolve in the future, can also be incorporated.

3.2 Simulation Study Procedure

The evaluation of the accuracy of the different valuation methods requires a comparison basis that can accurately calculate the different associated cash flows with high enough resolution.

This requires a mathematical representation of the power plants to allow modelling their power production with sufficient time resolution and to consider their energy outputs. Due to the volatility of renewable energy sources, the modelling of these needs to consider variability in the weather conditions linked to the energy generation.

Analyzing the combination of different power plants in a complex, multi-domain energy supply system, demands a more sophisticated approach that considers the interactions between the different components. The modelling of a distributed, cross-sector energy supply system requires the integration of different individual models. These models represent the several energy sources and sinks, and the relations between the different components. Existing approaches use simulation tools to model separate components to calculate their production and the total costs. The modelling requires a system-oriented approach and an hourly or quarter-hourly resolution to consider weather and price variations. The models shall allow analyzing different configurations of the energy supply for comparison. These requirements result in a demand for more sophisticated tools and approaches. Schmeling et al. (2020) analyzed tools for the integration of renewable energy into various energy systems. These approaches evaluate the technical performance of the energy supply system and use objective functions based on environmental or economic factors to evaluate their performance.

3.2.1 Modelling Objectives of ENaQ District Energy System

Schmeling et al. (2020) presented a tool for planning and decision-making for a distributed energy supply, as part of the project "Energetisches Nachbarschaftsquartier Fliegerhorst Oldenburg" (ENaQ). The developed model for the project ENaQ has as main objective to find optimal configurations for the case study of this district, located in Helleheide, in Oldenburg, Lower Saxony, Germany (Damm et al., 2019; Schmeling et al., 2020). Energy planning presents complex structures. Objectives are multidimensional and include decentralized energy supply systems connected to local energy supply grids. The district hosts approximately 110 housing units, each one with demands of electricity, space heating, and drinking hot water.

The objective of the development of the energy system for ENaQ is to be as climate friendly as possible yet affordable. It shall allow additional sector coupling and maximization of the self-consumption of locally produced energy. Therefore, the three different targets in the ENaQ project are the minimization of equivalent CO_2 emissions, minimization of annualized costs, and maximization of consumption of locally produced energy.

For a given configuration, the simulation calculations find the optimal energy flows that minimize the objectives. These calculations consider the individual power flows between the components in a complex energy system. CO_2 emissions are calculated using specific values of the different energy sources (DIN, 2019). Quantification of energy costs considers the different cash flows. Initial investments, maintenance costs, replacement costs, purchase and sales of electricity, and costs of fuels are accounted for and annualized (VDI, 2012).

3.2.2 Requirements of Energy Plants and Energy Systems

The operation of the energy system must fit certain boundary conditions: the location and the corresponding weather data, the values of energy price (such as electric energy day-ahead prices, fuel prices, and related values, as per Sect. 3.1, Step 7), the temperature for space heating and water heating, and the energy demand. This information serves as input data for the model. The ENaQ research project places high and very detailed demands on the functionalities of the energy system modelling and simulation software, such as:

- Mapping of the boundary conditions of meteorological data, electricity price, energy demands
- Modification of necessary technical-physical assumptions and basic economic assumptions

- Minimum time resolution of 15 minutes
- Externally control and parametrization of the software
- Consideration of the following energy use forms: heat, space heating, domestic hot water, and mobility
- Connection to energy supply grids, such as electric grid, gas grid, district heat grids
- Sector coupling
- Energy trading with external markets
- Flexibility for implementation and parametrization of local energy supply technologies, such as gas boiler, pellet boiler, photovoltaic, wind turbines, combined heat and power plants (CHP), geothermal sources, heat pumps, power to heat, electrolyzers
- Implementation of storage technologies: electric storage, water tanks
- Integration of different pricing scenarios and economic incentives for the calculation of economic indicators. Consideration of the local regulations (such as EEG[2], KWKG[3], EnEV[4], and EEWärmeG[5])
- Calculate economic indicators, such as Total Annual Energy Supply Costs
- Calculate ecological impacts, such as Total Equivalent CO_2 Emissions
- Calculate energy operation indicators, such as Degree of Autarchy or Self-Consumption

3.2.3 System Analysis of Modelling Components and Interactions

The development of the modelling of the ENaQ energy supply system began with an analysis of the possible technologies for energy supply and the exclusion of those deemed unfeasible by the project developers. A firstly developed model superstructure (Fig. 3) encompasses the considered technologies and the different external energy sources, with energy demands as sinks. For electricity, it is assumed that the energy system will purchase locally unsatisfied energy demand on the day-ahead market. The district energy system supplies also heat demand (Schmeling et al., 2020). Energy storage devices allow flexibilities.

Table 1 details the different components considered in the model superstructure. Due to the possibility of parametrization of the different values, multiple configurations can use the same structure for scenario analysis. Calculation of costs and cash flows requires additional information on investment costs, lifetime, replacement costs and periods, and maintenance.

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[2] Erneuerbare-Energien-Gesetz—German Renewable Energy Sources Act.

[3] Kraft-Wärme-Kopplungsgesetz—German Combined Heat and Power Act.

[4] Energieeinsparverordnung—German Energ Saving Ordinance.

[5] Erneuerbare-Energien-Wärmegesetz—German Renewable Energies Heat Act.

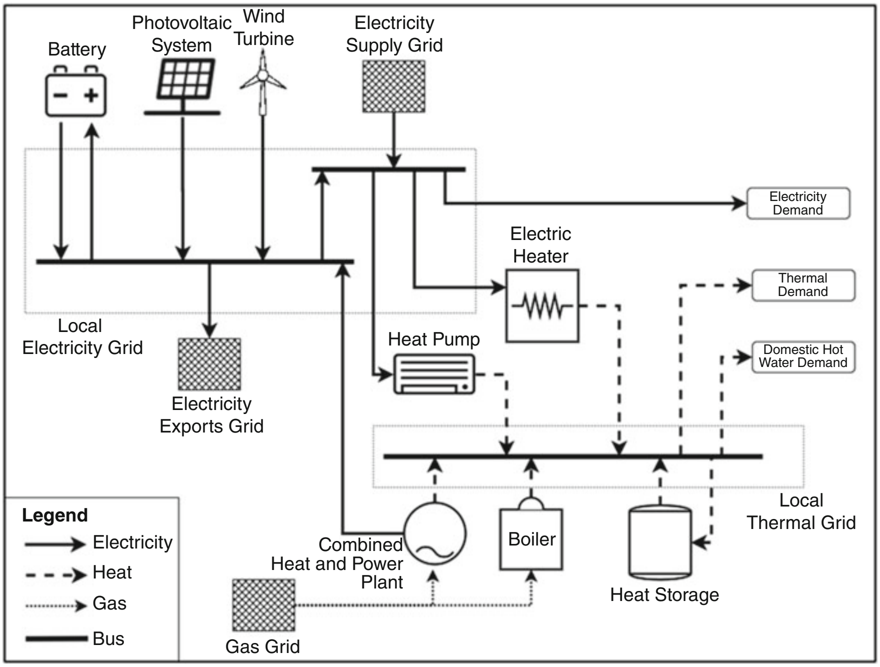

Fig. 3 Superstructure of the model. Adapted from Schmeling et al. (2020)

3.2.4 Model Formalization

Data sources for meteorological conditions come from local weather stations for reference years. Exchange sources, such as European Energy Exchange (EEX), provide information on electricity market prices. The configuration of the buildings and the potential residents' profile provide the basis for the synthetic load profiles are based on. The tool *LoadProfileGenerator* (Pflugradt, 2017) is used for the generation of electrical and domestic hot water demand curves. A combination of different tools generates heat demand profiles. The simulator uses this information as input. Models for each technology exist independently so that each one contains mathematical representations of the physical properties of the individual devices. These, for example, calculate the value of produced electricity by a given photovoltaic plant under certain weather conditions. These formal models of each technology account for efficiencies, conversion losses, dependencies on environmental factors, lifetime, or storage losses. The model integrates energy buses, which serve as balancing nodes of energy flows. The modelling tool then combines the different sources and sinks of energy to formulate the optimization problem for later solving. The results are required to be in the form of time series for each specified flow between components, nodes, sources, and sinks. Further post-processing calculates KPI based on the resulting energy flows and information on prices of energy carriers, energy market prices, specific costs and emission factors. The selected KPIs, based on the above-

Table 1 Component description for the superstructure of the ENaQ model

District Electric Supply	
Photovoltaic Generator (PV)	
Peak Power @ STC	kW
Efficiency @ STC	%
Inclination	°
Orientation	°
Funding Out Price	EUR/kWh
Wind Turbine Generator	
Installed Capacity	kW
Power Curve	kW vs. m/s
Funding Out Price	EUR/kWh
Combined Heat and Power Plant	
Nominal Electrical Power	kW
Nominal Thermal Power	kW
Efficiency @ LHV	%
Biogas fraction	%
Battery	
Capacity	kWh
Power	kW
Charge efficiency	%
Discharge efficiency	%
Self-Discharge	%/h
Cycles	n

District Thermal Supply	
Boiler	
Thermal power	kW
Efficiency @LHV	%
Geothermal Near Surface	
Area	m^2
Surface thermal potential	kW/m^2
Geothermal Deep	
Depth	m
Number of bores	N
Temperature	T
Geothermal potential	kW/m/K
Heat Pump	
Source temperature	K
Target temperature	K
Thermal power output	kW
Nominal COP	1
Heat Storage	
Volume	m2
Temperature	K
Thermal losses	%/day
Pellet Boiler	
Thermal power	kW
Efficiency @LHV	%
Electric Heater	
Power	kW
Efficiency	%
Solar thermal	
Area	m2
Inclination	°
Orientation	°
Temperature	K

Boundary Data	
Weather	
Air temperature	K
Soil temperature	K
Wind speed	m/s
Direct normal irradiance	kWh/m^2
Direct horizontal irradiance	kWh/m^2
Energy Demand Profiles	
Electricity	kW vs. time
Space heating	kW vs. time
Domestic hot water	kW vs. time
Natural Gas, Biomethane	
Cost	EUR/m^3
LHV	kW/m^3
CO_2 specific emission	$kgCO_2/m^3$
Diesel	
Cost	EUR/l
LHV	kW/l
CO_2 specific emission	$kgCO_2/l$
Pellets	
Cost	EUR/kg
LHV	kW/kg
CO_2 specific emission	$kgCO_2/kg$
Electric Grid	
Day-ahead price	EUR/kWh
Intra-day price	EUR/kWh
Specific CO_2 emissions	$kgCO_2/kWh$

mentioned modelling objectives, are (1) annual energy costs, (2) equivalent CO_2 Emissions, and (3) self-consumption of locally produced energy.

3.2.5 Model Implementation

Schmeling et al. (2020) found that proprietary simulation environments were insufficient to meet the ENaQ requirements since these were unable to model the interaction of the mentioned components adequately. This favored an open-source approach. Among the solutions examined, oemof.solph, part of the Open Energy Modelling Framework (oemof), proved to be the best modelling tool. oemof.solph transforms the energy flows in the system into a linear optimization problem, where the objective function can be specified to the modelling targets, which can then be solved by a numerical solver (Krien et al., 2020).

3.2.6 Experimentation

The experimentation modifies the input parameters on the configuration of the energy system. Synergy effects can occur in energy systems with different components. The value of the overall system can differ from the respective values of the individual plants. It is then important to investigate how sensitively the model reacts to the parametrization of the marketing options. Relevant parameters are the general electricity price development, the CO_2 certificate prices, the development of the specific investment costs of the respective technologies, and the associated fuel costs.

4 Results

To perform this quantitative validation of valuation methods, it is necessary to apply both the valuation methods and the presented simulation. The results will be used in the benchmark to calculate the KPI. The reference values are to be calculated using the simulation.

4.1 Benchmark

In benchmark step 7 the indicators were developed. To determine the deviation of reference values from the results of the evaluation methods for KPI 1 and 2, the root mean square percentage error was used (see formula 10). In the following formulas, the results of the evaluation methods have the index VM and the reference values from the simulation model have the index R.

$$\mathrm{RMSPE} = \sqrt{\frac{100\%}{n} \sum_{i=1}^{n} \Delta x_{\mathrm{rel},i}^2} \tag{10}$$

The KPI 1 for the revenues generated on the respective markets *Revenue* will be calculated using formula 11.

$$\Delta x_{\mathrm{rel},i} = \frac{\mathrm{Revenue}_{VM,i}}{\mathrm{Revenue}_{R,i}} - 1 \tag{11}$$

The KPI 2 for the full load hours *OperationHours* will be calculated using formula 12.

$$\Delta x_{\mathrm{rel},i} = \frac{\mathrm{OperationHours}_{VM,i}}{\mathrm{OperationHours}_{R,i}} - 1 \tag{12}$$

The KPI 3 for the correlation coefficient $r_{VM,I;R,I}$ of the cash flow sequences of the respective markets will be calculated using formula 12.

$$(1 - r_{VM,i;R,i}) \times 100 \tag{13}$$

Based on these KPIs, a quantitative validation of the valuation methods can be carried out. These KPIs can be used to evaluate the individual valuation methods and their ability to reflect specific technologies. The individual KPIs provide conclusions about the inherent advantages and disadvantages of the respective evaluation methods.

4.2 Simulation

This section details the required changes needed in the current structure of the model to work as an experimentation tool for providing a quantitative basis for the benchmark, so the reference parameters in Eqs. 10–13 are calculated.

4.2.1 Objectives Definition

The goal of the model developed for ENaQ is the optimization of the energy system configuration within the district with consideration of the already mentioned indicators. The purpose was different from that of directly analyzing the valuation of individual or combined power plants. Instead, a form of this valuation was integrated into the analysis and post-processing of results of energy flows. In its current form, the model results post-processing can perform the calculation of total costs of energy for the given timeframes. This functionality can be adapted to estimate the valuation of an energy system configuration, which also deals with investment costs and cash flows. Calculation of the total costs requires monetization of equivalent CO_2 emissions. The objectives of the model shall then be redefined to "calculate the total financial valuation of an energy system, with consideration of the related CO_2 emission costs."

4.2.2 Additional Model Requirements

The model developed for ENaQ overlooks the inclusion of information required for valuation presented in Sect. 2.1. Therefore, the model needs to consider the following information:

1. Intraday Markets
2. Future Markets
3. CO_2 Emissions Certificate Markets
4. Flexibility
5. Hard Coal Plants
6. Brown Coal Power Plants
7. Combined Cycle Plants
8. Gas Power Plants

- **Data:** Additional data is required to calculate the valuation of the energy system under the different methods. Data is required on:

1. CO_2 Emissions Certificate Prices
2. Base price
3. Peak price
4. Intra-day market price
5. Spot market price
6. Future electricity price development
7. Flexibility prices
8. Subsidies to electricity production through renewable sources
9. Residual value of components
10. Degradation of efficiency
11. Evolution of price of energy carriers (gas, coal, pellets)

- **Components:** The model currently lacks the possibility of deciding regarding markets. Data files provide statically the information of energy prices the beginning of the calculations. This overlooks market options since no algorithmic decision to consider different markets exists. The model would require modifications to allow consideration of several markets and their variable prices. Formulation and incorporation of these alternatives for the objective functions will account for different market options. Additionally, markets for flexibility are currently absent in the model. The model needs then to incorporate these components. Components representing fuel power plants, such as coal power plants, are also missing.
- **Formalization:** The model needs to include pricing schemes and price data to integrate the different market information and the costs of emissions. In its current state, the model calculates for a period of 1 year, with annualization of investment costs. This overlooks parameters such as future price development, degradation of energy efficiency or depreciation of devices. The post-processing of the results requires an expansion to correspond to those of the different valuation methods to include the results for further comparison.
- **Implementation:** An implementation can start using the existing superstructure of the model, with the newly added components representing different markets as objects with specific constraints. This requires the modification of

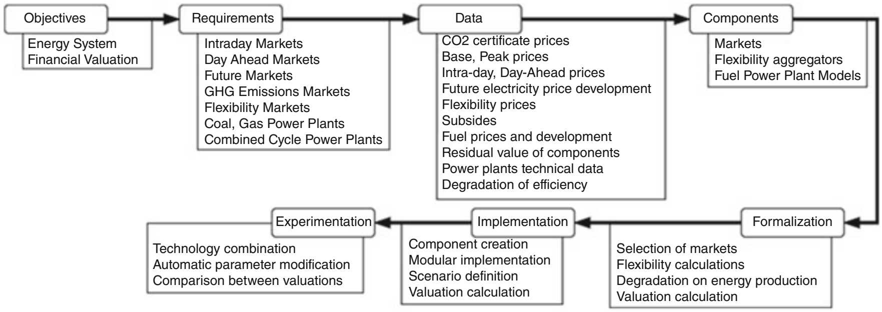

Fig. 4 Requirements for adaptation of the ENaQ model for calculation of valuation

the structure of the electric energy supply, which so far considers inputs from the electric grid and outputs of locally produced exceeding energy to a single market with day-ahead pricing information. For further scenario development, the current structure also requires implementation of components representing the different markets and the additional types of power plants. The post-processing needs to include a module to calculate the valuation of the power plants according to the methods described in Sect. 2.1.

- **Scenarios and Experimentation:** The modified model shall allow the development of several scenarios for experimentation and evaluation of valuation of power plants, which can provide a baseline for validation of the valuation methods. This shall allow an analysis of multiple power plants and a combination of them. This requires the creation of a controlling interface that allows automatic modification of parameters, and modification of scenarios based on the energy market scheme selected. A comparison of the different valuation methods with these baselines will then be possible and can provide a quantitative evaluation of their results. Figure 4 summarizes the required modifications to the existing model.

5 Conclusion

This paper presented an approach to validate valuation methods quantitatively. Thus, this approach addresses the research gap presented by Wehkamp et al. (2020). The research gap presented included factors in the context of valuation methods that significantly limit the applicability of existing valuation methods in the current energy sector. This paper proposes a tool for validation of the valuation methods done via a benchmark and a simulation model. The benchmark compares KPI developed within the benchmark process. To calculate the results, it is necessary to apply the valuation methods to several technologies and simulate the model to gain the reference values. The KPI are then used to evaluate the results of the valuation methods results by comparing them to the validated reference values.

A simulation of the behavior of the power plants and the energy markets can produce analysis with a sufficient degree of precision and with a high enough time resolution. The simulations are oriented to calculate the optimal flows of energy required to minimize or maximize objectives, in this case, energy costs. Due to the high level of detail resulting from a simulation, this is a valid starting point to provide a baseline. It is pointed out that the simulation model is only used for the benchmark, but does not represent a practice-relevant valuation method in this context. Simulations are often a very laborious undertaking. This is due to the high level of detail and the need for interdisciplinary expertise required for such an approach. In the valuation practice, such an effort exceeds the actual benefit of such valuations. This applies in the sense of the adequacy for purpose principle.[6]

From the authors' point of view, there is a need for further research in the development of valuation methods to address the existing criticism in the literature and in practice. Furthermore, the attempt to introduce a quantitative validation of valuation methods by means of a simulation-based benchmark requires further examination.

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An Expert Review of the Social Media Analytics Framework for Citizen Relationship Management

Khulekani Yakobi, Brenda Scholtz, and Benjamin Wagner vom Berg

Abstract Social Media Analytics (SMA) has brought new improvement and development opportunities to aid decision-making for government and to support e-governance and smart city projects such as Citizen Relationship Management (CzRM). The purpose of this paper is to report on the expert review interviews conducted to verify the Social Media Analytics Framework (SMAF) for CzRM. This framework was designed based on the Systematic Literature Review (SLR) approach. The expert review consisted of online interviews with five experts from the field of Computer Science and Information Systems (IS). Qualitative Content Analysis (QCA) using Atlas.ti was conducted to organize the data, facilitate coding and identify themes. The findings from the review verified the five components of the framework, which are: Success factors and guidelines for SMA; The research domain of CzRM; The data process phases and methods; Methods and tools for SMA; and Decision-making and Social Media Intelligence (SOCMINT). Future work will further validate the framework through focus group discussions and an extant systems analysis.

Keywords Citizen relationship management · Data value chain · Decision-making · e-governance · Expert review · Social media analytics · Social media intelligence

1 Introduction

South Africa is classified as a developing country and is still in the infancy stage of digital, social, and ecological transformation (Weaver et al., 2017). The challenge of development and transformation related to service delivery and poverty in national,

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provincial, and local municipalities has not yet been overcome (Masiya et al., 2019). South African citizens' economic class is ranked at middle-income status and half its citizens still lack adequate nutrition, water, energy, shelter, health care, and education (Beyers, 2016). A study conducted in public service delivery by Nkomo (2017), highlighted that more South Africans complained that municipalities performed "very badly" in maintaining roads with a proportion of 56% responses, maintaining marketplaces 55%, managing land use 54%, and maintaining health standards 50%. Information and Communications Technology (ICT) can provide solutions for some of these challenges by making use of social media data related to service delivery and support of socioeconomic development (Roztocki & Weistroffer, 2019). The emergence of social media use by citizens holds benefits related to Citizen Relationship Management (CzRM) and e-participation that might address the challenges of e-governance.

The use of social media has brought some new ways of communication and complaints of citizens on government service delivery. As noted in the study conducted by Stieglitz et al. (2014), social media have experienced tremendous growth in their user base. Recently, Chae et al. (2020) reported that the use of social media has revolutionized all areas of business and, in many instances, and it has shown fundamental changes between companies/governments and their customers/citizens. However, social media data is noisy and unstructured, and organizations struggle to extract knowledge from this data and convert it into actual intelligence (Sivarajah et al., 2017). The use of SMA has shown benefits to derive and extract intelligence from unstructured data on social media platforms. SMA tools can both monitor Social Networks (SNs) and perform sentiment analysis for improved decision-making. Jackson and Bazeley (2019) argue that NVivo is a useful and appropriate tool when it comes to monitoring content on SNSs with cheaper costs incurred as compared with other available SMA tools. For sentiment analysis, uClassify can be used as an appropriate tool (Okauh, 2019).

Whilst much research has been conducted regarding SMA, there is limited evidence on how SMA can provide a framework that can aid decision-making for government. The main problem identified in this paper is that existing SMA and Big Data Analytics (BDA) models and frameworks do not provide guidelines for tools and methods in general and are not specific to the context of CzRM and/or service delivery. The main question to be answered in this paper is *"How can the adoption of SMA framework support decision making in the context of CzRM."* This paper forms part of a larger study that aims to propose an SMA framework for decision-making in CzRM that will provide SMA tools, methods, and guidelines. These can be adopted by decision makers in government in order to improve decision-making related to service delivery. The paper presents the first version of the Social Media Analytics Framework (SMAF) for CzRM, which is evaluated by experts and the feedback was used to improve the framework for the project going forward. The findings will be used to guide researchers and practitioners since the SMA framework addresses challenges faced by governments, and therefore the success of SMA projects can be improved.

The following section provides the methodology that was followed during the expert review. The third section provides an overview of the proposed framework with its main components. The fourth section provides an analysis of the findings. Finally, conclusions are drawn and future study recommendations are made in the fifth section.

2 Research Design

Three research methods were used to answer the research question. The first method used was the Systematic Literature Review (SLR) method, which was used to design the theoretical framework, i.e., the SMAF for CzRM. The next method was the expert review method proposed by Skulmoski et al. (2007). The review was conducted as a series of interviews in order to get feedback on the SMAF for CzRM by experts. The method used for the data analysis was qualitative content analysis. These three methods are explained in the following sub-sections; however the main focus of this chapter is the reporting of the expert review process and the findings of this review.

2.1 The SLR

An SLR approach (Higgins et al., 2003) can assist with identifying, evaluating, and interpreting all available research relevant to the research questions/objectives. The following five comprehensive steps of an SLR proposed by Khan et al. (2003) were adopted in this research and were: (1) Framing questions for a review; (2) Identifying relevant work; (3) Assessing the quality of studies; (4) Summarizing the evidence; (5) Interpreting the findings. The findings from the SLR were used to design the first version of the SMAF for CzRM.

2.2 The Expert Review

An expert review is a process of interviews that is used as an efficient and concentrated method to collect narrative data while shortening the time of accessing key practical knowledge in a particular field (Bogner et al., 2018). The first step of the review involved the selection of experts for interview. The target profile of experts used in this study was based on four criteria that were proposed by Skulmoski et al. (2007) for an expert review process namely: Knowledge and experience relevant to the research; Capacity and willingness to participate; Sufficient time to participate; and Effective communication skills. The experts in this review were therefore required to have the following attributes:

- A Doctor of Philosophy (Ph.D.) qualification
- Research expertise related to the field of Computer Science and/or Information System (IS)
- A minimum of 5 years of experience working on this relevant research expertise
- Published articles in the respective field
- Involvement in government projects for SMA/BDA, service delivery, and/or CzRM; and
- Sufficient English level of communication

The researcher drafted a formal letter describing the purpose of the expert review and the target profile and distributed it to all prospective experts via email. Prospective experts were those identified through contacts of the researcher and promoter of this study and who agreed to participate. Out of six identified experts, only five agreed to take part. After the experts confirmed their availability and date, the researcher set up the interview meetings for each using Microsoft Teams and distributed the link for the meeting together with three documents: the Background Information form; the Proposed Framework document (see Sect. 3) and the Guidelines for SMA Incorporation into CzRM for Decision-Making (see Table 2) so that the expert could be prepared to answer questions regarding the framework during the interviews.

The participant profile summary is presented in Table 1, one of the experts is an Associate Professor and the Head of the Department of IT and Management from Daffodil International University in Bangladesh. Another expert is a Professor and Director from the University of Cape Town (UCT) in South Africa. Three experts are

Table 1 Expert reviewers profile

Experts	Job title/ position	Work experience (years)	Level of expertise on IS or computer science research	Level of expertise on government projects/ research	Research fields and focus
ER1	Assistant Lecturer	3	4	4	SMA tools
ER2	Post-Doctoral Researcher	15	4	5	Smart cities, social media, and sustainability
ER3	Associate Professor	29	3	4	Programming and community engagement
ER4	Associate Professor and Head of Department	11	4	4	Data science, business analytics, and technostress
ER5	Professor and Director	38	3	5	Addiction E-government and ICT4D

from the Nelson Mandela University (NMU) in South Africa; one was an Assistant Lecturer, the second was a Post-doctoral Researcher, and the third was an Associate Professor. All experts had published research material related to the field with varying years of experience. Four of the experts have a PhD, but the participant without the PhD (ER1) had specialist expertise in SMA tools since his Master's Dissertation was on SMA tools and he has practical and technical experience in working with SMA tools. The experts ranked themselves on a scale from 1 = Novice to 5 = Expert on the level of expertise on IS or Computer Science research as well as on the level of expertise on government projects/research related to SMA/BDA, service delivery, and/or CzRM.

The interviews were carried out over 3 weeks between November and December 2020. The duration of the interviews was approximately 1 h each. The Expert Review Interview Guide was the research instrument, which included questions derived from the SLR and those related to the components of the framework. The interviews were recorded using the Microsoft Teams recording function tab, and the videos were downloaded after each interview for transcription. The recorded interviews were transcribed. Qualitative data analysis using Atlas.ti version 9 was used to organize the data, facilitate coding, and identify themes.

2.3 Qualitative Content Analysis

The expert review interview data was analyzed using Qualitative Content Analysis (QCA). The steps that were performed during this analysis process were those proposed by Erlingsson and Brysiewicz (2017). The first step was to extract the meaning units and was based on the study aim and research question. In the second step, the meaning units were condensed for to shortening the text while still preserving their core meaning. In the third step, a code was generated as a label to a name that most exactly describes the particular condensed meaning unit. In the fourth step, a category was formed by grouping together those codes that are related to each other through their content or context. In other words, codes were organized into a category when they describe different aspects, similarities, or differences, of the text content that belong together. Assarroudi et al. (2018) believe that the constant comparison of generic categories and main categories results in the development of a conceptual and logical link between generic and main categories, nesting generic categories into the pre-existing main categories and creating new main categories. Therefore, codes identified during the content analysis process were grouped and categorized according to their meanings, similarities, and differences. The products of this categorization process are known as "generic categories" (Elo et al. 2014). In the last step, themes are identified. A theme is an expression of an underlying meaning, i.e., latent content, found in two or more categories. Through the steps, the researcher endeavored to systematically transform the large bodies of text and present it in higher levels of abstraction as themes.

3 Proposed SMAF for CzRM

The design and development of the framework in this chapter was based on the findings from the SLR (Khan et al., 2003). The framework is illustrated in Fig. 1 and consists of the following five components:

- Success factors and Guidelines for SMA (Table 2)
- Research domain of CzRM
- Data value chain phases
- Methods and tools for SMA; and
- Decision-making and SOCMINT

The first component relates to the success factors and guidelines for SMA (see Table 1). These were based on the five challenges in the Stieglitz et al. (2018) framework, which were extended to the 23 success factors identified through the SLR. All of these factors were identified in studies in the context of government, decision-making, Big Data/social media or SMA. The success factors (F1 to F23) were then reworded as guidelines, since if these success factors are adhered to, the success of an SMA project can be improved. The guidelines were classified into three categories based on those used in the data lifecycle of Sivarajah et al. (2017), namely: Data (characteristics), Process, and Management. Data success factors are in purple text, Process are in italics, and the rest are management factors. The guidelines were also classified according to the Technological, Organizational, and Environmental (TOE) theory constructs (Tornatzky & Fleischer, 1990). The TOE framework resides as one of the theories to test technology usefulness and identifies three aspects of an organization's context that influence the process by which it adopts, implements, and uses technological innovation (Ruivo et al., 2016). The Technological context helps to describe both internal and external technologies relevant to the organization. The organizational context provides descriptive measures in the organization. Thirdly, the environmental context refers to the arena in which an organization conducts its business. The guidelines in the Data and Process category were classified within the Technology construct since, all of the data and process guidelines related to tools or technology or technological methods. Only the Management category had factors in all three contexts of TOE.

From the literature reviewed 23 factors were identified; 20 of these were related to Big Data or SMA in studies conducted in countries outside of Africa. An additional three factors were identified from studies conducted in an African context.

The second component is based on the research domain component of Stieglitz et al. (2018), which in this case is the context of CzRM. It is essential that the framework considers this context and therefore caters to citizens' needs and behaviors in this second component. Engaging citizens in the CzRM process should be supported not only to improve public service delivery through ICT but also enables governments to better engage citizens in what is referred to as "e-participation." E-participation helps the government to use available and advanced technologies to support active citizenship and enable more informed citizens on issues related to

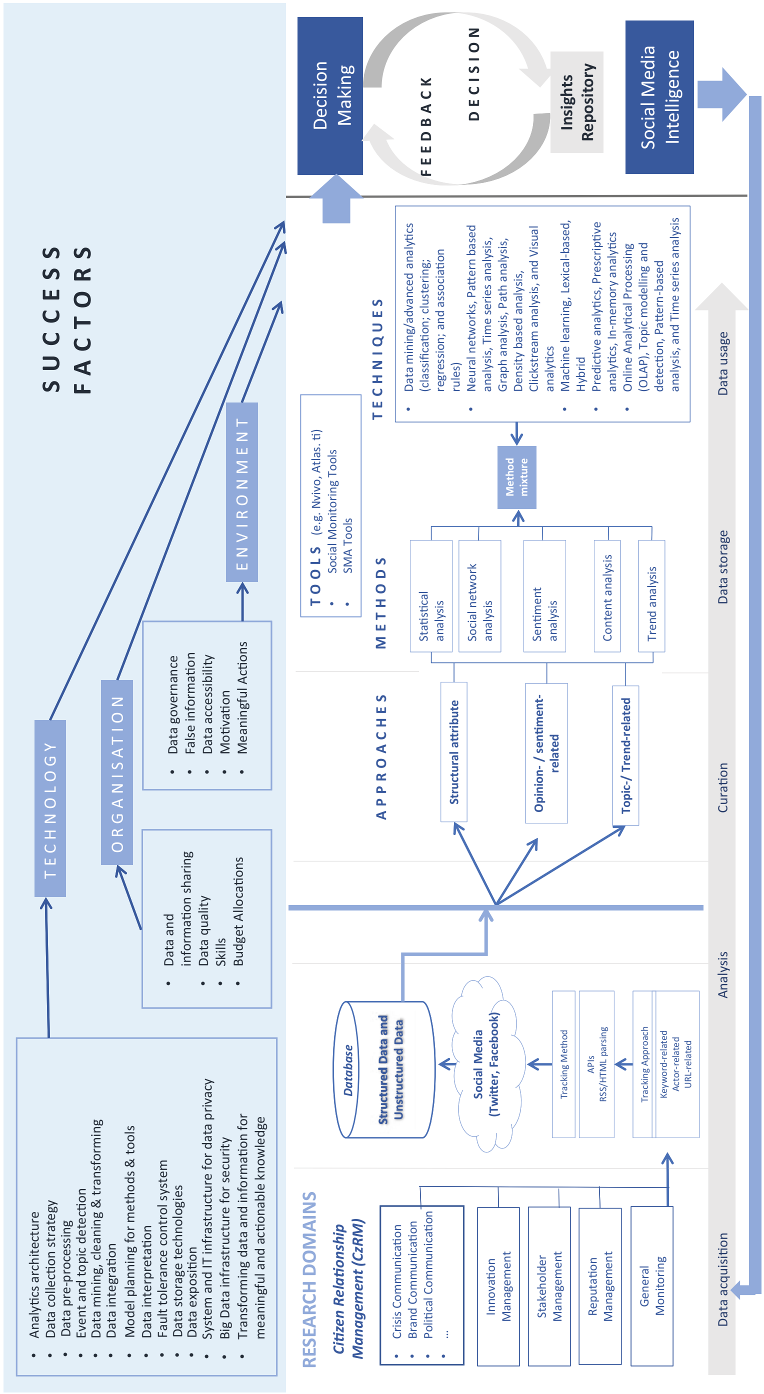

Fig. 1 SMAF for CzRM (Author's own source—extended from [Stieglitz et al. (2018)]. Findings

Table 2 Success factors and guidelines for SMA incorporation into CzRM for decision-making

Category/phase DATA (technological)	Code	Success factors	Guidelines	Sources
Characteristics and architecture	**F1**	SMA as analytics architecture for big data	Government should prioritize an analytics architecture for SMA, because it will provide a suitable technique to analyze social media data to support their decision-making processes and service delivery for citizens. It also holds potential to cater for both historic and real-time data simultaneously	Anuradha (2015), Rajaraman (2016), Uddin and Gupta (2014), Mishra et al. (2015)
Process (technological)				
Data acquisition	**F2**	Data collection strategy	Government should develop data collection engines to homogenize data of heterogeneous data sets. A data collection strategy, based on data set annotation, governs collection and pre-processing. The personnel should use SMA methods and tools to analyze acquired data and measure the activities of citizens from social media through data warehousing	Hofman (2015), Holsapple et al. (2014)
	F3	Reliable data sources for event and topic detection	Government should potentially link or fuse heterogeneous data sets from social media to improve data quality and ensure reliability of data source for event and topic detection. The government use on SMA should be measured using valid and reliable standards and measures for social media effects	Holsapple et al. (2014), Risius and Beck (2015), Stieglitz et al. (2018)
Data analysis	**F4**	Data pre-processing methods and techniques	Government should use data pre-processing tools that will enable the user to treat and process complex data. To implement pre-processing to data, python and R are among the most popular programming languages	García et al. (2016), Li (2019)
	F5	Capabilities to mine, clean, and transform social media big data	The data mining pipeline should be used as an integration of all procedures in a data mining task. It will be useful for government to extract data from unstructured, multi-media data sets using SMA. After data successful mining, government should ensure capabilities to clean social media data based on data set annotations and transform social media data to a common format with known semantics into quality data (referred to as data big value)	Cai and Zhu (2015), Hofman (2015), Li (2019), Sivarajah et al. (2017)

(continued)

Table 2 (continued)

Category/phase DATA (technological)	Code	Success factors	Guidelines	Sources
	F6	Integration of social media data into big data strategy	Integration and aggregation of social media data into big data strategy for government goals should allow the combination from different social media data and its use to enhance CzRM	Gioti et al. (2018)
	F7	Model planning for SMA methods and tools	Government should implement a model to use SMA methods and tools for analyzing components such as patterns, time series, graphs, text, path, density, and clickstream for citizens	Jenkins (2019)
	F8	SMA methods and tools to interpret data for intelligence and value	Government should adopt SMA methods and tools and techniques for systematic mapping to recognize interesting patterns and correlations from social media data. Government should also gain the capacity to handle multiple languages (both linguistic and programming)	Byarugaba Agaba et al. (2016), Kapoor et al. (2018), Sivarajah et al. (2017)
Data curation	**F9**	Fault tolerant control systems	Government should design a fault controller/fault system that will be a key component for large-scale processes to meet high standards performance, reliability, and safety	Arrichiello et al. (2017), Mishra et al. (2015), Patra et al. (2013), Roxana and Eva-Henrietta (2017), Yan-feng et al. (2015)
Category/ phase process (technological)	**Code**	**Success factors**	**Guidelines**	**Sources**
Data storage	**F10**	Data storage technologies	Government should adopt data storage technologies, such as columnar stores and clever combinations of different storage systems using (the Hadoop distributed file system (HDFS)), as these are generally considered to be efficient and less expensive	Strohbach et al. (2016).
Data usage	**F11**	Data exposition strategy	Government should use well-defined SMA methods and tools as a data exposition strategy for sharing and exposing insight, and knowledge generated from data that could be considered in decision-making process	Faroukhi et al. (2020).

(continued)

Table 2 (continued)

Management				
Technological	**F12**	System and IT infrastructure for data privacy	Government should have IS specialists to design a system and IT infrastructure for privacy and provide control measures for regulation of information and data from social media	Fenwick et al. (2016), Kanchi et al. (2015), van den Hoven et al. (2014)
	F13	Big data infrastructure for integrity and reactive security	Social media big data integrity and reactive security should be also designed and implemented to address technology disruptors	Jaseena and David (2014), Moura and Serrão (2015)
Organizational	**F14**	Data and information storage sharing	Government should enhance competence of using appropriate platforms for data and information storage to share and integrate key information across the organization	Curry (2016).
	F15	Quality of decision-making alignment	The quality of decision-making must be aligned with data management and data governance	Cohen (2016), Kenett and Shmueli (2014)
	F16	Skills to manage privacy and security of social media data and for interdisciplinary analysis	Researchers and analytics personnel must have the skills to manage unintended breaches of privacy and to apply security measures when analyzing social media data, to enable decision-making effectiveness and other skills. The skills are necessary for interdisciplinary considerations to analyze social media	Cao and Duan (2014), Ram et al. (2016), Stieglitz et al. (2018)
	F17	Allocation of budget for big data management	Government should prioritize the allocation of budget for cost and operational expenditures during management of big data	Hammer et al. (2017)
Environmental	**F18**	Data/information as a high-priority asset for governance	Information and data should be treated as corporate assets and given the same priority as human and financial assets. Therefore, governance measures should be ensured by government to manage information and data	Hartley (2015)
	F19	Accurate information for service delivery	The accuracy of information from social media should be clearly considered as citizens' complaints and could lead to better service delivery	Höchtl et al. (2016)
	F20	Access to insightful information from social media	Government should ensure the access to insightful information from social media by using trained personnel on SMA methods and tools for accessing and drawing insights from social media data as a reliable source	Hussain and Vatrapu (2014)

(continued)

Table 2 (continued)

Category/ phase	Code	Success factors	Guidelines	Sources
Success factors/guidelines for African countries				
Technological	**F21**	Transforming data and information into meaningful and actionable knowledge	Government should ensure data processing technologies are set in place to transform data and information for actionable knowledge	Bumblauskas et al. (2015), Sivarajah et al. (2017)
Success factors/guidelines for African countries				
Management	**F22**	Motivation to use social media platforms	Government should educate the older generation in motivation to also use social media platforms as its features is evident to help the younger generation to improve their personal growth with active, creative, and cooperative learning experiences, and increased interaction with people	Alhabash and Ma (2017), Sanmamed et al. (2017)
	F23	Managing efforts of activists for a meaningful action when using social media	Government should ensure that the purpose of the internet campaign is to involve users in solving a particular problem or informing them about the existence of such a problem	Sokolov et al. (2018)

service delivery (Al-Dalou & Abu-Shanab, 2013). Thus, consideration of the CzRM domain is an important opportunity for efficient service delivery and the vital aspect of citizens' engagement that uses effective communication channels like social media (del Mar Gálvez-Rodríguez et al., 2018).

The third component is the data process phases and methods and is based on the Stieglitz et al. (2018) framework, which was extended to incorporate the full data value chain proposed in the Big Data value chain as described by Curry (2016). In this component, the framework considers the handling of diverse data sources with heterogenous data through data warehousing approaches to ensure that only the high-value fragments of the data are processed by the data-warehouse analysis. The storage of citizen data should allow a valid and reliable measure for social media effects to align their social media initiatives with organizational strategies and goals and ultimately create business value (Risius & Beck, 2015).

The framework considers all possible types of source social media data and storage infrastructure to cater for the intelligence stage in the Process category and these types of sources are based on the constructs considered in the Modified B-DAD Framework proposed by Elgendy and Elragal (2016). Possible data sources and formats include: transactional/operational data; relational data; social media; text; images; videos; audio; graphs; rich media; XML; key/value pairs; clickstream files; system log files; sensor data; mobile/ GPS data; internet data; satellite data;

geospatial data; and streaming data. Social media platforms such as Twitter (political election campaign, political movement, strategies for tourism on cultural heritage, and topic models) and Facebook (political revolutions, communication, and health delivery) are considered in the framework. Consideration of social media platforms and campaigns will help the government to redirect the usage and improve skills on the most used social media platforms and campaigns. Stieglitz et al. (2018) proposed that data visualization could provide a meaningful role between structured and unstructured data.

The fourth component focuses on approaches, methods, techniques, and tools to address the lack of research on methods and tools for SMA. This component extends the Stieglitz et al. (2018) framework with the addition of some techniques for each method as well as several tools proposed by Okauh (2019). Okauh (2019) argues that monitoring on SNSs allows for quick access to valuable information on users' profiles, awareness, liking, preference, and interests. His study identified four popular tools related to social media monitoring, which are: Atlas.ti; NVivo; Brand24; and Keyhole. Okauh (2019) focused on the sentiment analysis method of SMA and identified six tools as recent, popular tools for sentiment analysis found across most research portals and websites. These tools are: SentiStrength; Semantria; uClassify; Text2Data; RapidMiner; Brand24. Each of these tools allows users/decision makers to analyze opinions, sentiments, attitudes, and emotions from written texts on SNSs.

The last component refers to the decision-making and Social Media Intelligence (SOCMINT) component, which was added to the Stieglitz et al. (2018) framework, motivated by the theory that improved decision-making can lead to intelligence (Ivan et al., 2015). SOCMINT emerged as a relevant discipline for governments because it is described as being able to improve the quality of decision-making by reducing ignorance (Omand et al., 2014). With attempts to reduce ignorance, SOCMINT can reduce the "unknown" that comes within any decision-making equation (Ivan et al., 2015). SOCMINT is a recently coined term for the confluence of ideas from Open Source Intelligence (OSINT) and web mining techniques (machine learning and database methods) applied to social media data to identify and understand those situations from social media environments characterized by the behavior of individuals that would affect national security (Şuşnea & Iftene, 2018). The component design was also based on (1) the Model of BDAIA effect on decision-making of Adrian et al. (2018) that proposed three dimensions (organization, people, and technology) that are related to TOE and reported on as impacting decision-making in the BDAIA framework and, (2) the Modified B-DAD Framework proposed by Elgendy and Elragal (2016) that includes monitoring and feedback. Therefore, social media intelligence can be achieved by monitoring social media and performing SMA.

The findings of the expert review interviews were presented based on the main five themes that were derived through the steps of QCA proposed by Erlingsson and Brysiewicz (2017). The expert review questions were based on the proposed framework components.

3.1 SMA Success Factors

Four of the five experts agreed that all the 23 success factors represented SMA success factors appropriately and comprehensively. However, the following recommendations were made:

(a) *African success factors*—Two experts were concerned about the motivation for considering African success factors separately as they believed that they were also applicable to other countries.
(b) *Types of decisions*—Quite often, the decision-making process is fairly specific to the decision being made. Some choices are simple and seemingly straightforward, while others are complex and require a multi-step approach to making the decisions (Ejimabo, 2015). One expert (ER5) proposed the addition of types of decisions as a success factor, since this can influence the other factors that are relevant. The inclusion of decision-making type as a critical success factor is also supported by the decision-making theory proposed by Milkman et al. (2009), which guides decision makers on specific choices. Milkman et al. (2009) observed that for the optimal and best options among many choices in the decision-making process there are four types of processes that could assist decision makers to make this choice:

- Group decision-making process
- Individual decision-making process
- Organizational decision-making process; and
- Meta organizational decision-making process

This input from ER5 confirms that the types of decision-making process are major factors that might contribute in influence decision-making through the decision-making choices: political decisions; personal decisions (including medical choices, romantic decisions, and career decisions); and financial decisions (Ejimabo, 2015).

(c) *Decision-making styles and cognitive processing*—The expert ER5 also proposed adding decision-making styles and cognitive processing as success factors. Decision-making styles are triggered by the cognitive processing of the individual decision maker, either through the decision maker's perceptions, attention, memory, categorization, problem-solving etc. This becomes a major issue for government as many political factors might influence cognitive processing for decision styles. The decision-making styles should be evident by the consideration of the cognitive processing of decision makers at the managerial level. The importance of the decision-making process of human behaviors by which a preferred option or a course of action is chosen from among a set of alternatives based on certain criteria should be emphasized. Wang and Ruhe (2007) suggest that the cognitive process of decision-making may be applied in a wide range of decision-based systems such as cognitive informatics, software agent systems, expert systems, and decision support systems. Gilboa et al. (2018) highlighted that a decision theory offers a formal approach to decision-making, which is often viewed and taught as the rational way to approach managerial decisions, especially in organizations such as government.

(d) *Data storage technology*—It was noted by ER5 that the term “data storage technology” does not clearly explain the success factor and that it therefore needs additional describing attributes such as provision of redundancy, security, availability, scalability, and high-transferring rate. ER5 suggested that maybe there should be a rephrasing of the data storage technology factor to describe the factor more clearly.

(e) *Government* vs. *private organization*—The expert ER5 stated that there is a difference between government and private organizations in terms of operations. The difference of these entities could result in some slight differences in the success factors that might be found within their organizational space. He therefore recommended that the specific context of government should be highlighted more clearly in the framework.

3.2 SMA Success Factors Classification Based on Data Lifecycle and TOE

The majority of experts agreed with the SMA success factor classification based on the data lifecycle (Data, Process, and Management) proposed by Sivarajah et al. (2017). However, two experts recommended that the categorization of the phases be made clearer. ER5 stated that the three data lifecycle categories were not the only ultimatum approach; he emphasized that other available approaches can be used as well.

For the Data category, ER5 stated that whilst unstructured and structured data was shown in the framework, external and internal data should be added. Poleto et al. (2015) observed that making use of Big Data is powered by internal and external data sources so that organizations can make use of Business Intelligence (BI) strategies and tools to aid in identifying relevant information. ER5 also suggested that there should be some additional success factors under the Data category, such as the Big Data characteristics (7Vs).

All experts agreed with the adoption of the TOE for the classification of factors in the Management category. ER5 suggested that some changes should be made to the TOE-related factors. Amongst the suggestions of changes was that some technological factors could have been put under the Data and Process phases. All environmental factors should be moved as well to organizational factors. Three additional factors were suggested by ER5 to include as environmental factors, these were national and international data regulations and policies (Protection of Personal Information Act (POPIA) and General Data Protection Regulation (GDPR) Act); industry vendor support; and maturity of technologies. POPIA is an example of South African national data and information policy to be considered as an environmental factor since it promotes a sense of confidence and information integrity. This confirms the studies of Mabunda (2021) and Netshakhuma (2019), that any organization that does not consider the POPIA when dealing with data might face challenges such as unprotected personal information from unauthorized disclosure. Governments should sustain industry vendor support and maturity of technologies for sustainable tools, skills, and services for the environment. ER3, ER4, and ER5 specifically indicated different concerns related to the Management category under TOE. ER5 stated that organizational readiness, top management support, and training programs should be added as important variables under the Management category.

3.3 SMA Guidelines for Each Success Factor

All experts agreed that the list of guidelines for the success factors should not be shown on the model as it will make it too cluttered. ER3 stated that it would be ideal if a table of references could be provided when referring to the model. ER5 partially agreed and provided a suggestion that the guidelines should be made electronic or clickable for customization purposes.

3.4 Methods and Tools for SMA

ER4 highlighted that there should be a specific algorithm that should be identified as a technique; for example, in prescriptive analytics, it could be decision trees or linear regression. The use of algorithms becomes a vital technique to bring solutions for informed decision-making. This confirms what Stieglitz et al. (2018) indicated that software architecture brings the solutions as they were specifically designed to handle social media Big Data that mostly focus on data storage technology and the algorithms used to process the data for effective decision-making. Two of the experts (ER1 and ER5) stated that the statistical analysis method and the in-memory analysis technique should be reconsidered as they felt that these techniques were not significant and were redundant for SMA.

All five experts agreed that SMA tools are very important in aiding decision-making. Two experts agreed that considering SMA tools for both social media monitoring and performing analysis will help gain comprehensive knowledge for intelligent decision-making. ER5 stated that intelligent decision-making will depend on the quality of data generated the quality of use of the tools and the understanding of the decision maker. ER5 suggested that he will rather consider decision-making to be evidence-based not necessarily intelligent in his opinion. Data quality has also been highlighted as a critical factor in the SMAF for CzRM and Broo and Schooling (2020) suggest that the integration of multiple data sources often requires accessing accurate and consistent data, consolidating different data representations, and eliminating duplicate information. Therefore, the quality of data should be considered attentively.

3.5 General Input on the SMAF for CzRM

The experts highlighted some recommendations for improving the framework, in terms of scientific concepts, design, and layout of the proposed SMAF for CzRM. These were as follows.

(a) *Structural improvements*—ER3 stated that some restructuring of the diagram sections within the framework was recommended to clearly show the relationships of concepts and arrows. The experts expected to see the significant display of the data value chain within the proposed SMAF for CzRM. ER2 also noted that the font size of the framework components and concepts should be increased for more visibility and readability.

(b) *Social media platforms*—ER5 suggested that the SMAF for CzRM should draw on specific social media platforms that are going to be used in the framework and specific details on how these are going to be used at a provincial level.

4 Recommendations for Improving the SMAF for CzRM

The findings from this paper revealed several opportunities and recommendations for both practice and for the research community. For practice, government departments could benefit from adopting the proposed framework to assist with planning SMA projects and to support decision-making related to citizen service delivery. The proposed SMAF for CzRM offers SMA methods and tools that can assist government managers with understanding their citizens' needs better, enable them to interact more intelligently with them. The government can measure citizens' activities through monitoring social media data, and analyze this data using SMA tools to gain better insight into service delivery issues and citizen complaints or other input. The adoption of SMA can increase opportunities and create new ways of data analytics for democratic participation. The framework can also provide guidance on how to analyze social media data patterns, trends, and topics related to citizen posts to enable informed and insightful decision-making. Understanding social media data is vital because social media facilitates new ways of knowing citizens' behavior. The alignment of Big Data to SMA goals within government will create value from unstructured data. The generated value will enhance a viable smart city project that could be responsive to citizens' needs and behavior.

The recommendations for researchers are that the framework could be used to guide researchers in other projects in the field of SMA. The TOE theory was successfully used to classify these guidelines within its three constructs of Technological, Organizational, and Environmental. These guidelines are a contribution to the SMA research community especially within the context of government. However, one limitation of the study was that none of the experts were working in government, so the input was more from a theoretical angle.

Future research could adopt the guidelines in a government department or in other contexts and evaluate the impact thereof. Future research could also investigate the impact of adopting these guidelines on the decisions related to CzRM made by managers.

The paper has presented a framework that provides SMA guidelines, tools and methods in the context of CzRM. A major finding of this paper was based on the evaluation of the first version of the proposed framework with the feedback received from the experts. The feedback confirmed the main components of the framework and highlighted necessary improvements. In the Data category, the importance of an analytics architecture for SMA in the context of CzRM was highlighted and is a key factor for SMA and decision-making success as it will support the effective analysis of social media posts from citizens related to service delivery. This architecture should cater for both historic and real-time data at the same time. In the Process category, the data collection strategy can be considered as vital to homogenize data of heterogeneous data sets, and potentially link or fuse those data sets, as well as improve data quality to ensure the reliability of data sources. Government personnel could be assisted by the framework guidelines for each phase in the data value chain to support the use of SMA tools to analyze and measure the activities of citizens on social media networks. In the Management category, guidelines on the management of technological innovation within government were viewed through the lens of the TOE theory constructs. It is also important that governments should have IS specialists that will be responsible for designing a system infrastructure for privacy and should provide control measures for the regulation of information and data from social media.

5 Conclusion and Future Directions

This paper forms part of a larger study and extends the work of Stieglitz et al. (2018) by designing a decision-making framework to support CzRM by incorporating SMA. The main theoretical contribution is the five components of the proposed framework that were derived through the SLR approach. The paper has addressed the gap in research by proposing an SMA framework that offers guidelines, methods, and tools for informed and data-driven decisions in the context of CzRM. The TOE theory proposed by Tornatzky and Fleischer (1990), the data lifecycle theory proposed by Sivarajah et al. (2017), and the data value chain theory of Curry (2016) were successfully used as a lens to view the findings of the SLR and to classify the guidelines and can be an aid to determine the usefulness of the TOE aspects to consider in an SMA project.

The verification process confirmed the framework and its components, and also resulted in some new additional success factors and variables that will be added to the improved framework in future research. The improved framework is envisaged to offer comprehensive results on how to adopt and use SMA for decision-making, service delivery, and/or CzRM. When the government capitalizes on the use of

SMA, SMA projects will be successful. Managers and decision makers in government can use the framework together with the guidelines, to guide them with improving the success of SMA projects. The guidelines can be used by researchers to undergird studies into the success of SMA and smart city projects within the field of CzRM. Understanding the techniques and approaches available and the features provided by SMA tools can help governments to prioritize support services for e-government services and activities. Managers can be made more aware of the potential of SMA to assist them with their decision-making processes and ultimately to improve CzRM, particularly service delivery.

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Complexity of Epidemics Models: A Case-Study of Cholera in Tanzania

Judith Leo

Abstract Timely prediction of Cholera epidemics is essential for preventing and controlling the size of an outbreak. Over the past years, there have been great initiatives in the development of Cholera epidemic models using mathematical techniques, which are believed to be the most powerful tools in developing mechanistic understanding of epidemics. Despite the existence of these initiatives, the timely prediction of Cholera is still a great challenge. Recently, the World Health Organization reported that "the global burdens of waterborne epidemics from environmental factors are expected to increase over-time with an increase of epidemic size." Due to these challenges, this paper reviewed existing Cholera mathematical models and observe that they have limitations/complexities, especially when working with many variables. The use of how machine learning (ML) can be used to overcome the limitations/complexities, such as lack of effective integration of environmental factors, such as weather are investigated. Hence, the study developed an ML reference model and its development procedures, which can be used to overcome the existing complexities. The results indicate at an average of 87% that the developed measures can integrate a large number of datasets, including environmental factors for the timely prediction of Cholera epidemics in Tanzania.

Keywords Cholera epidemics · Machine learning (ML) · Environmental factors · Developing country

1 Introduction

An epidemic is a rapid spread of an infectious disease to a large number of people in a given area within a very short period of time (Brauer, 2017). It is generally caused and transmitted by several factors, including weather conditions, population activities as well as other geographic and biological conditions (Constantin de Magny

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et al., 2008). Epidemiological traditional statistic models, which are also called epidemic complex models, have been powerful mechanisms in developing a clear understanding of epidemic outbreaks. They can provide a detailed prediction of an epidemic outbreak, such as the size of the outbreak, which is of considerable public health significance (Siettos & Russo, 2013). Epidemiological complex system modeling of infectious diseases is well explained in the literature, and the need for these models is obvious (Bora & Ahmed, 2019). However, it has been noted in several works that most of the epidemiological complex system models are simplified by describing the transmission or prediction of disease through individuals. This is because; modeling diseases that are transmitted directly from person to person is relatively simple through the use of the Susceptible, Infected and Recovered (SIR) complex model, which gives an adequate prediction of the way, it will spread (Harko et al., 2014).

The World Health Organization (WHO) report has stated that the global burden of diseases from environmental factors is expected to increase substantially over time, with the emergence of new epidemics and an increase in epidemic outbreak sizes. In addition, it was estimated in the WHO report that environmental factors alone are responsible for an estimated 24% of the global burden of disease in terms of healthy life years lost, and 23% of all deaths; children being the most affected (Remoundou & Koundouri, 2009). Furthermore, each year, 13 million or nearly a quarter of all deaths worldwide result from environmental causes related mainly to water, sanitation, and hygiene, indoor and outdoor pollution, harmful chemicals, such as pesticides, and global climatic change (Frumkin & Haines, 2019). These environmental risk factors are avoidable, preventable, and play the causative role of more than 80% of diseases, including waterborne epidemics that are routinely reported to the WHO (Neira & Prüss-Ustün, 2016).

Due to these reasons, the role of environmental factors and population dynamics as determinants of epidemics has currently become an area of increasing interest to ecologists, statisticians, epidemiologists, clinicians, public health experts, Information and Communication Technology (ICT) experts, Ministries of Health and Social Welfare and Meteorological Agencies (Xu et al., 2015; Galea et al., 2010). In this paper, environmental factors are defined as the major factors in the environment, which can cause widespread epidemics. Without proper attention and management of the environmental risk factors, it will be difficult to achieve the effort of the Sustainable Development Goals (SDGs) towards eradicating epidemics, such as Cholera (Fitzpatrick & Engels, 2015).

Cholera is one of the epidemics in developing countries, as shown in Fig. 1, which has links with the environmental factors and can be spread through drinking contaminated water or through person-to-person transmissions (Weill et al., 2017). The disease is caused by bacteria, which thrives in periods of excessive rainfall and high air temperatures (Shapes, 2015). Given that both extreme heat and more intense storms are expected to increase due to global climate change, researchers anticipate that Cholera outbreaks could become more frequent in the future (Weill et al., 2017). Despite the major advances in research, the prediction of Cholera transmission and outbreak in relation to weather change, still remains a challenge in the modern

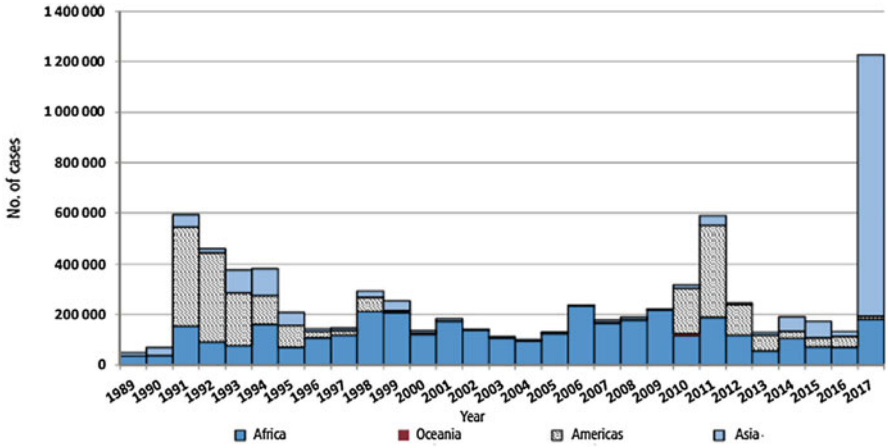

Fig. 1 Cholera cases reported by WHO by year and by continent 1989–2015 (Deen et al., 2020)

medical world, since many models have not explicitly included all necessary environmental, social, and other variables that affect the growth and spread of the bacteria. The lack of inclusion of these variables into the models may be due to the resulting complexity; which makes the models costly in terms of their computation time and difficult to solve (Thessen, 2016).

In view of this brief introduction, this paper aims at reviewing the status and challenges of existing Cholera epidemic models, and to propose suitable measures to overcome and complement the existing complexities or challenges, by taking advantage of emerging technologies, such machine learning (ML) techniques. The remainder of the paper is organized as follows; Sect. 2 discusses the literature review of Cholera epidemics models. Sect. 3 explains the methodology used in the process, whereby the study conducted experiments on the running time of popular Cholera models to determine and compare their actual/computational running time on Cholera data from the Dar-es-Salaam region in Tanzania. Sect. 4 briefly presents results and their discussion on how ML techniques can be used to (i) overcome the limitations and complexities of the existing models, (ii) enable the integration of a large number of datasets or variables from other factors including environmental factors, and thus (iii) enable prediction of epidemics at a faster and larger scale, and lastly, Sect. 5 concludes the paper.

2 Literature Review

2.1 Related Research

Cholera is caused by *Vibrio cholerae (V. cholerae),* usually as a result of drinking contaminated or dirty water (Fung, 2014). This organism thrives in the aquatic environment, and most researchers have noted that high air temperature and periods

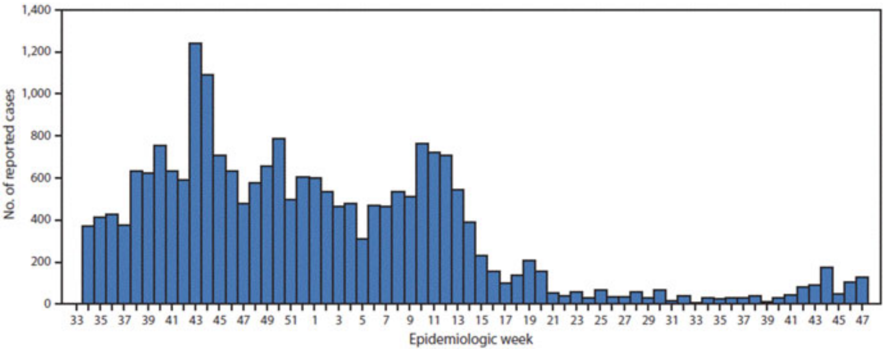

Fig. 2 Ongoing Cholera epidemic—Tanzania, 2015–2016 (Narra et al., 2017)

of excessive rainfall create environmental conditions that favor the bacteria's growth (Leckebusch & Abdussalam, 2015). In dry conditions, river levels decrease, and then, the bacteria accumulate in dangerously high concentrations. During excessive rainfall, flooding can spread the bacteria to regions that have not previously been infected, resulting in fast-spreading Cholera epidemics (Constantin de Magny & Colwell, 2009). It is anticipated by researchers that, the number of Cholera outbreaks is expected to rise in the future as a result of climate change, especially in developing countries, including Tanzania (Weill et al., 2017).

Tanzania is a developing country in Sub-Saharan Africa (SSA) with frequent recurrences of Cholera waterborne diseases (Lugomela et al., 2015). It was reported that the first Cholera epidemics cases in Tanzania were in 1974 with a Case Fatality Rate (CFR) of 10.5%. The first major Cholera outbreak happened in 1992 with 18,526 cases and 2173 deaths with CFR of 11.7% (Narra et al., 2017). Due to integrated disease surveillance and response strategy between 1998 and 2010, the Cholera outbreak size reduced to CFR of 2.7%. Nevertheless, in 2015, an outbreak occurred due to the Burundi refugee crisis, which led to the majority of refugees fleeing to Tanzania, which in return led to overcrowded and unhygienic camp conditions (Green, 2015). Another major incident of the Cholera epidemic occurred from August 2015 to April 2016 with a total of 14,608 cases and 228 death incidences in the Dar es Salaam region (Narra et al., 2017), as shown in Fig. 2. Such a long-term occurrence of epidemic diseases is a great threat to the country, its neighboring countries, and the world at large (Bwire et al., 2016; Picarelli et al., 2017).

Dar es Salaam region has also proven prone to flooding, which has led to several major Cholera outbreaks, which may threaten the country's economic prosperity. The current processes in the region for tracking environmental determinants, which are related or linked to the cause of epidemics are mostly manually based and in different sources of information systems, to the extent that epidemiologists, ecologists, and statisticians fail to obtain an appropriate predictions for early warnings, which could enable effective interventions to be done at the right time (Darcy et al., 2015). Therefore, there is a high need to formulate a mechanism that will be effective and innovative enough to counteract the problem (Kwesigabo et al., 2012; Mghamba et al., 2011). The developed mechanism can be used as a reference model by other modelers or researchers when designing and developing models for Cholera waterborne epidemics in other developing countries. Hence, due to the presented status of Cholera disease in Tanzania, the Dar es Salaam region was chosen as study area.

2.2 Overview of Cholera Epidemics Complex Models

This section identifies and reviews some of the existing Cholera epidemics models. The section presents both models which have and have not incorporated or integrated environmental factors in their formulation and then, discusses briefly their strengths and weaknesses in the prediction of Cholera outbreaks.

Capasso and Serio (1978) are among the very first modelers to formulate the development of a well-known Cholera model, which has not integrated the aspect of the environmental factors as determinants for prediction and transmission of the outbreak. Their model has assisted in the formulation and extensions of other successful models and also provided knowledge on how the Susceptible, Infected, and the Recovered population is linked to the transmission of Cholera disease (Capasso & Serio, 1978). In addition, there are other several Cholera epidemics models, which have only extended this model by incorporating additional variables such as education, immunity to the Susceptible population, age of the population, and economic factors to mention a few (Lund et al., 2015). In fact, these models have assisted in a clear understanding of the Cholera epidemics in various dimensions. However, these models lack the reality touch since they have not incorporated the environmental factors, such as water bodies, seasonal weather changes, *V. cholerae* behavior in certain areas of the environment, which are essential factors in determining the transmission rate, prediction value, and causes of Cholera epidemics in the area (Picarelli et al., 2017).

Among the first Cholera dynamics model which linked environmental aspects in its formulation was conducted by Claudia Torres Codeco (Codeço, 2001). In this paper, the model will be referred to as Codeco Model. The Codeco Model is a Cholera epidemics mathematical model, which has considered aquatic reservoirs as the only environmental determinants for transmission of Cholera epidemics. Table 1 explains the variables and parameters used in the formula and Fig. 3 is the compartmental diagram of the Codeco Model.

The Codeco Model has incorporated few variables and uses a basic Susceptible-Infected-Recovered (SIR) approach coupled with an aquatic population of *V. cholerae*. The objective of this model was to explore the role of the aquatic reservoir on the persistence of endemic Cholera as well as to define minimum conditions for the development of epidemic and endemic Cholera. Due to the incorporation of the aquatic reservoir as one of the environmental factors or determinants, the model contributed to the proper explanation of the rate at which Cholera

Table 1 Symbols used in the Codeco Model (Codeço, 2001)

Symbols for Variables	Description
S	Number of susceptible people
I	Number of infected people
B	The concentration of toxigenic *V. cholerae* in water (cells/ml)
H	Total human population
N	Human birth and death rates (per 1000 people)
K	The concentration of *V. cholerae* in water that yields a 50% chance of catching cholera (cells/ml)
Symbols for parameters	
A	The rate of exposure to contaminated water (per 1000 people)
R	The rate at which people recover from cholera (per 1000 people)
Nb	The growth rate of *V. cholerae* in the aquatic environment (per 1000 people)
Mb	The loss rate of *V. cholerae* in the aquatic environment (per 1000 people)
E	The contribution of each infected person to the population of *V. cholerae* in the aquatic environment (cell/ml per 1000 people person^{-1})

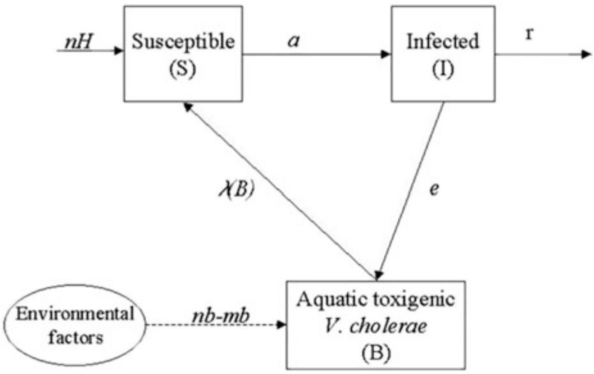

Fig. 3 Compartmental diagram of Codeco Model (Codeço, 2001)

is transmitted in the community as a product of social and environmental factors. The model has also shown the importance of understanding the effect of the aquatic reservoir in the transmission and dynamics of Cholera, which depends on the sanitary conditions of the community. In addition, the model recommended further development of a better understanding of *V. cholerae* ecology and Cholera epidemiology. However, the model has not explicitly integrated all essential environmental factors, such as temperature, rainfall, and humidity levels of the area and as a result, it is very difficult to provide a quantitative prediction on Cholera dynamics (Codeço, 2001). Nevertheless, this model brings some new insights into Cholera epidemiology on essentially quantifying prediction of Cholera dynamics into a large aspect.

Similar scenarios occur in most of the other developed and implemented Cholera models. For example, Cholera models were developed by Wang and Modnak (2011) and Andam et al. (2015) to model Cholera dynamics with control strategies. These models have simply extended the Codeco Model by incorporating variable C as the control factor with the aim of gaining useful guidelines to effective prevention and intervention strategies against Cholera epidemics. The variable C has been used as a control measure to represent the effect of vaccination, therapeutic treatment, and water treatment. Lastly, the study reviewed Stephenson's Cholera epidemic model (Stephenson, 2009). Stephenson's model is, in fact, a SIR model extended with loss of immunity (a return flow from recovered to susceptible after an average of 6–10 years), with different degrees of illness, mortality, and with a reservoir to harbor the *V. cholerae*. The formulation of this model contains consequently a number of implicit assumptions such as constant weather seasons throughout the years and also many possibly relevant factors, including births, deaths, and detailed geographical locations of the area, are omitted. The study has also, observed that these models have not integrated explicitly essential environmental factors, such as the level of temperature, rainfall, humidity, wind, social-economic factors of the patient, geographical location of the area, and their surroundings to assist in the understanding of Cholera transmission in the area.

2.3 Overview of Machine Learning (ML) Models in Healthcare

There are a number of applications for ML techniques in disease analysis. The first ML is used to formulate sophisticated algorithms to "learn" features from a large volume of healthcare datasets, and then uses the obtained insights to assist clinical practice, such as to inform the proper patient care, reduce diagnostic and therapeutic errors and assist in making real-time inferences for health risk alert and health outcome prediction (Brauer, 2017). The study was done by Constantin de Magny and Colwell (2009) to demonstrated how different ML algorithms for diagnosis and analysis of different diseases such as heart, diabetes, liver, dengue, and hepatitis diseases can be used to promote improved accuracy of perception and decision-making processes. As it has been noted that in medical science, disease diagnosis and analysis are very serious tasks, hence through the assistance and adoption of the methodologies used in the algorithms of this study, modelers are able to get insight on how they can enhance the analysis of various diseases. For example, the study was done by Hoens and Chawla (2013) on the use of the Naive Bayes ML algorithm has proved to analyse heart disease Ali et al. (2015) at 86.419% of accuracy using 500 patients' data at the diabetic research institute in Chennai. In addition, formulated a hybrid technique by joining generic and Support Vector Machine algorithms using a wrapper approach in order to analyze five different datasets from Iris, diabetes, breast cancer, heart, and hepatitis diseases. The process of joining two algorithms increases the analysis accuracy to 80% for Iris disease, 78.26% for diabetes, 76.20% for breast cancer, 84.07% for heart disease, and 86.12% for hepatitis disease. Furthermore, Chieh-Chen Wu and his colleagues (Wu et al., 2019) diagnose the prediction of fatty liver disease using ML algorithms. Then, the performances of the three algorithms were compared and the FT Tree algorithm was selected as the best algorithm among the others in terms of its accuracy, performance, and speed.

As it has been noted earlier that the most effective way for managing disease outbreaks or epidemics is to detect them at early stages, then control and treat them through proper planning strategies and interventions before they occur or spread to a large area. For this reason, there has been a significant study in considering the application of ML techniques in disease prediction. For example, it was noted that millions in the United States suffer from undiagnosed or late-diagnosed type-2 diabetes, therefore, Fung (2014) developed a type-2 diabetic predictive model using logistic regression, random forest, and neural networks in order to predict earlier the occurrence of the disease and then, facilitate preventive healthcare intervention, which in turn can lead into cost savings and improved health outcomes. The other model was developed by Picarelli with her colleagues (Picarelli et al., 2017) to predict the Cholera cases using an artificial neural network in Chabahar city in Iran. The model was capable of forecasting Cholera cases among 465 villages of the test group with an accuracy up to 80%.

3 Problem Formulation and Methodology

3.1 Problem Formulation

In summary, the literature review observed that most of the Cholera epidemics models use complex system model techniques. By definition, a complex system or mathematical model is a formalization of relationships between variables in the form of mathematical equations (Choisy et al., 2007). Mathematical modeling was invented after mankind realized the limitations of their brains to store and process large amounts of data (Kelly, 2015). Therefore, mathematics provided them with models that can approximate reality using data reduction techniques. Furthermore, they can describe different aspects, interactions, and dynamics that are happening in real world through mathematics (Quarteroni, 2009).

Due to their capacity, complex models have been used in various activities especially in understanding the dynamics of different epidemics. However, they have some limitations which lead to their complexities. First, some Cholera epidemic complex models focus on getting the formulation of a frontier in a classification problem, and therefore, they involve a lot of equations and assumptions, which sometimes lead to the problem of being unrealistic (Richardson, 1979). Secondly, some Cholera epidemic complex models are very complex in terms of usability; thus it needs a user to have knowledge of complex models in order to interpret and understand their result formulation (Prantzos, 1998; Akman et al., 2016; Mapoka et al., 2013). Thirdly, some of the existing Cholera deterministic complex models have limited the number of variables or parameters in order to be comprehensible and solvable (avoid complexities), hence as the result, the prediction value also decreases. Fourthly, it is hard to include a variable in the model since it always requires reformulating the model's equation (Choisy et al., 2007; Richardson, 1979). Hence, they do not work well with large datasets or variables (Thessen, 2016). In addition, the higher the number of datasets or variables in the Cholera epidemics mathematical models, the higher the complexity of the equations in terms of solving, iteration, interpretability, cost and also, computational performance in terms of speed to mention a few (Bradley et al., 2008). In this study, the high computational performance is referred to as high computational complexity or running time of the model to complete its computation or full cycle. Lastly, in the current direction where the world is moving to, there is a lot of unmanageable volume and complexity of big data. As a result, it is complex to work with Cholera mathematical models in some areas due to their limitations, and hence, there is a need to explore other techniques which will support and complement the useful task done so far by the mathematical models (Leskovec et al., 2014).

Nevertheless, it was interesting to note that there are limited studies that have investigated the use of ML in the prediction of diseases in African countries (No et al., 2021). This proves that the use of ML in the health sector especially in developing countries is at its infancy stage. As it was demonstrated in this study and looking at its functionalities and benefits such as; the use of ML has the potential in improving disease analysis, epidemics prediction, and decision-making processes. In addition, ML as a field of Computer Science can provide systems with the ability to automatically learn and improve from experience without being explicitly programmed (Jordan & Mitchell, 2015). Its process of learning begins with observing data, such as instructions and direct experiences, in order to observe patterns in the data and make a better decision for future applications. Machine learning evolved from the study of pattern recognition and computational learning theory in Artificial Intelligence (AI) and it is one of the fastest-growing areas of computer science, with far-reaching applications, as it teaches computers to do what comes naturally to humans and animals.

Furthermore, ML is closely related to computational statistics and mathematical optimization, which also focuses on prediction processes through the use of computers and delivery methods, theory, and application domains to the applied field (Tzanis et al., 2006). Moreover, ML explores the study through the construction of algorithms that use computational methods to learn information directly from data without relying on a predetermined equation as a model. The ML algorithms adaptively improve their performance as the number of samples available for learning increases. Therefore, ML algorithms are used every day to make critical decisions in medical diagnosis, stock trading, energy load forecasting, and many other applications (Dietterich, 2009). The prediction and accuracy results of ML can be improved through the use of several strategies. Some of these strategies are algorithm tuning, ensemble, and extreme feature engineering (Abuassba et al., 2017). Also, it is undeniable that ML is capable of solving the nature of the problem that we have around our societies such as missing information and imbalance data challenge (Nongxa, 2017).

3.2 Methodology

The research study applied qualitative and quantitative approaches and followed the waterfall model SDLC to develop the model following the proposed design of a conceptual framework for the reference model and its development procedures. In developing the focus group discussion and interviewer-administered questionnaire, the study adhered to the research questions posed by the study, especially during the literature review. The focus group discussions and interviewer-administered questionnaires focused on the following topics; knowledge on Cholera management and its interventions, the relationship between Cholera and environmental factors, existing initiatives, and their challenges in timely prediction for Cholera epidemics, and ML models for disease prediction. The focus group discussions and interviewer-administered questionnaire as shown in the appendix were deployed and administered to five hundred (500) as described in Table 2. The focus group discussions were limited to a maximum of 20 participants in order to ensure equal participation. Audio recorders, mobile phones, and laptops were used in recording, transcription, and coding the discussions and interviews. The participants include medical officers, epidemiological analysts, nurses, environmental experts, ICT and Mathematics experts, and Cholera patients from the Dar es Salaam region in Tanzania.

The dataset for the model development was collected from Dar es Salaam region in Tanzania. The daily seasonal weather changes data was collected from Tanzania Meteorological Agency (TMA), which was from January 2015 to December 2017; the Cholera cases data was collected from the Ministry of Health, Community Development, Gender, Elderly and Children (MoHCDGEC), which had 6800 observations with 3 variables and the wastewater distribution was collected from Dar es Salaam Water Supply and Sanitation Authority (DAWASA) as described in Table 3 in terms of variables.

In order to achieve the intended goal, the Adaptive Reference Predictive Model (ARPM) followed the conceptual framework design and the development procedure as briefly explained in Figs. 4 and 5. In this procedure, the Scikit-learn modules were imported, then, the dataset was loaded into the module. After that, the dataset was checked if it is well balanced. It was observed that the dataset was not well balanced, then, a sampling procedure was applied through the use of Adaptive Synthetic Sampling Approach (ADASYN) and Principal Component Analysis (PCA) in order to restore sampling balance and dimensions of the dataset. Then, the sampled dataset was randomly divided into two parts of 70% of data to be used as training datasets and the remaining 30% of the data as testing datasets. Then, 30-fold cross-validation as a test method was performed in order to reduce variability, over-fitting, and selection bias (Domingos, 2012). Thereafter, the training data were used to train

Table 2 Participants' profile and characteristics

Participant's characteristics	Total sample ($N = 500$)	Percentage distribution (%)	Description
Age in years			
≤18	85	17	The average age group for the study was 26 years old
19–30	330	66	
≥31	85	17	
Occupation			
Trader	50	10	Participants with features such as Trader, Artisan, Farmer, Salary Worker and Unemployed fall under Patient Cluster
Artisan	20	4	
Farmer	60	12	
Salary worker	30	6	
Medical expert	200	40	
Environmental expert	50	10	
ICT, ML & Maths expert	50	10	
Unemployment	40	8	
Education level			
Primary	100	20	Secondary consisted of participants with junior and senior high school levels at a ratio of 3:2, respectively
Secondary	110	22	
Certificate level	30	6	
Diploma level	40	8	
University	200	40	
Non-formal education	20	4	Non-formal education consisted with participants who do not have any kind of education
Cluster level			
Patient	200	40	Strictness was applied in selecting all participants based on five clusters. Therefore, there were no participants under the non-clustered category
Medical experts	200	40	
Environmental experts	50	10	
Environmental experts	50	10	
ICT, ML & Maths expert	0	0	
Non-clustered			
District			
Kinondoni	100	20	The study unbiasedly considered all districts in Dar Es Salaam regions. In addition, equal distribution of participant ration was highly considered
Temeke	100	20	
Ilala	100	20	
Ubungo	100	20	
Kigamboni	100	20	
Gender			
Female	300	60	Majority of participants were female at female to male ratio of 3:2
Male	200	40	

Table 3 Selected features for model development

Variables	Description	Measurements of variables
Daily seasonal weather changes data		
Temp_mean	Mean temperature	Degree Celsius (°C)
Rainfall	Rainfall	Millimeter (mm)
Humidity	Relative humidity	(%)
Wind_Dir	Wind direction	Degrees
Cholera cases data with regards to the patient details		
District	District location	Dar Es Salaam districts
DOS	Date on set	Date-month-year
LabResults	Laboratory result	Positive or negative
Water source type		
WasteWater	TreatedWater/CleanWater (1) and UntreatedWater/ DirtyWater (0)	1 and 0

and develop the models, whereas, the testing data were used to test the prediction performance of the developed models. In order to determine which ML algorithms were best able to predict (yes/no) whether cholera epidemic would occur given the weather variables, 10 classification algorithms were evaluated using F1-score, sensitivity and balanced-accuracy metrics. After, developing the model, the evaluation metrics were conducted in order to select the best performing models or algorithms. The Friedman-test (FM) was then used to determine whether the performance of the models was statistically significant. Then, the selection of the best-performing models using testing methods/techniques was performed. Lastly, if the process of selecting the best performing obtained more than one model as the results, then the model tuning process (ensemble) was performed repeatedly until the process obtains one best performing model.

4 Results

In this century, where the growth rate in dataset size is likely to grow faster than in the past due to reasons such as more time elapsed since record-keeping started, and more awareness of the need for real-time and evidence-based decision-making. Furthermore, big data has become one of the prime drivers in search of new data storage media, data extraction, data analysis, and forecast. Other drivers are the democratized access of cloud-based platforms, a broader spectrum of open source techniques, availability of labelled data, and increased access to capital (Kune et al., 2016). In connection with this situation, experts indicate that the health sector is facing a data explosion, in terms of a large amount of data for storage and the cost of managing the data Kwesigabo et al. (2012). In addition, currently, 90% of the medical data is not fully utilized, and looking at the case of climate change which may lead to more incidences of epidemic diseases and additional climatologically and environmental data to be integrated into health data analysis. Hence, it is important to explore the use of AI techniques in order to complement and support Cholera epidemics models which are normally developed through the use of mathematical models. In this paper, the study explored ML techniques as well as explored its functionalities and therefore, has proposed the development of a reference model, called Adaptive Reference Predictive Model (ARPM) to facilitate the development of data-driven waterborne epidemic models. The ARPM complements the existing complexities and limitations of the other existing Cholera epidemics models. The following subsection, briefly explains the significance of the proposed ARPM and the general features of machine learning models that are expected to be used during the development of ARPM. The study applied a mixed-design approach of quantitative and qualitative methodologies to propose the ARPM, development-procedure and the focus group discussion, and interviewer-administered questionnaire as shown in the appendix.

4.1 Significance of the Proposed ARPM

Any model intends to provide desired services based on the specific task (Lloyd, 2005). This scenario applies to the prediction of the Cholera epidemic cases which must be timely produced because it rapidly spreads to a large number of people (Symington, 2011). Based on the complexity of the reviewed Cholera epidemic mathematical models and the fact that we need to incorporate explicitly the essential environmental variables in the model, there is a very high chance of increasing the complexity and computational limitation of the model as proved in Sect. 4 of the results. Efficiency (time behavior) is one of the model's quality characteristics (Roberts et al., 2015). Hence, the study proposes the use of ML techniques for model development. This is because ML algorithms are capable of learning fast from trillions of observations, one by one, and without a need of making assumptions (Thessen, 2016). Also, they can work timely with data that have a wide number of variables, attributes, and a high number of observations (Johansson et al., 2013). The conceptual framework of the proposed ARPM is shown in Fig. 4.

A conceptual framework as defined by Farrow et al. (2021) and noted in Fig. 4 as the analytical and contextual way of presenting an idea, theory, knowledge in a way that is easy to understand, remember, and apply (Sustainable Accounting Standards Board, 2013). The ARPM will integrate datasets of Cholera epidemic cases; such as a patient's age, sex, home location, the date on set, lab result and his social-economic factors, seasonal weather changes; such as temperature, rainfall, wind, and humidity; and clean and wastewater distribution inward and district formats from the Ministry of Health and Social Welfare, Meteorological Agency, hospitals, Dar es Salaam Water Sewerage Corporation (DAWASCO) and the Ministry of Water and Irrigation. In addition, the ARPM will adopt features from Cholera mathematical models on how they prepare data and integrate them for successful prediction of Cholera epidemics. Moreover, machine learning techniques will be applied to develop the

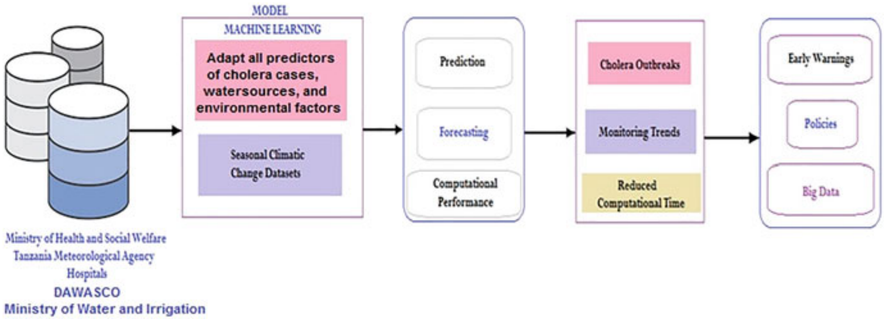

Fig. 4 Conceptual framework for ARPM

ARPM, and then its normal computational performance will be further optimized so that it can work better in larger datasets cases. Furthermore, the ARPM will have the following significances: (i) timely prediction of Cholera outbreaks which in return is a useful feature for early warnings and intervention; (ii) assist in evidence-based decision making; (iii) forecast monitoring trends that link the Cholera dynamics with seasonal weather change variability; (iv) aid value to the environmental and health-related policies; and (v) assist in big datasets due to its reduced complexity and computational time. Lastly, ARPM can also be used as a reference model by other researchers, modelers, or other users to develop other epidemic models related to waterborne epidemics apart from Cholera.

4.2 Results of Model

The following are results of the model, which followed the development procedure as described in Fig. 5. The results of FM showed that Random Forest, Bagging, and ExtraTree classifiers had the best performance, with 74%, 74.1% and 71.9% accuracy, respectively. Lastly, the ensemble method of model fine-tuning was then applied in order to obtain one model from the three, and an overall accuracy of 78.5% was achieved. These following Tables illustrate on how the final model was achieved starting from Tables 4, 5, 6, and 7.

4.3 Results of Validation of the Proposed Measures

Based on the focus group discussions and interviewer-administered questionnaire, the collected data was repeatedly cleaned and analyzed using Statistical Package for Social Science Software (SPSS). The results for Section B part of the questionnaire showed that at an average of 87% of participants strongly agreed, 10% Agreed, 1%

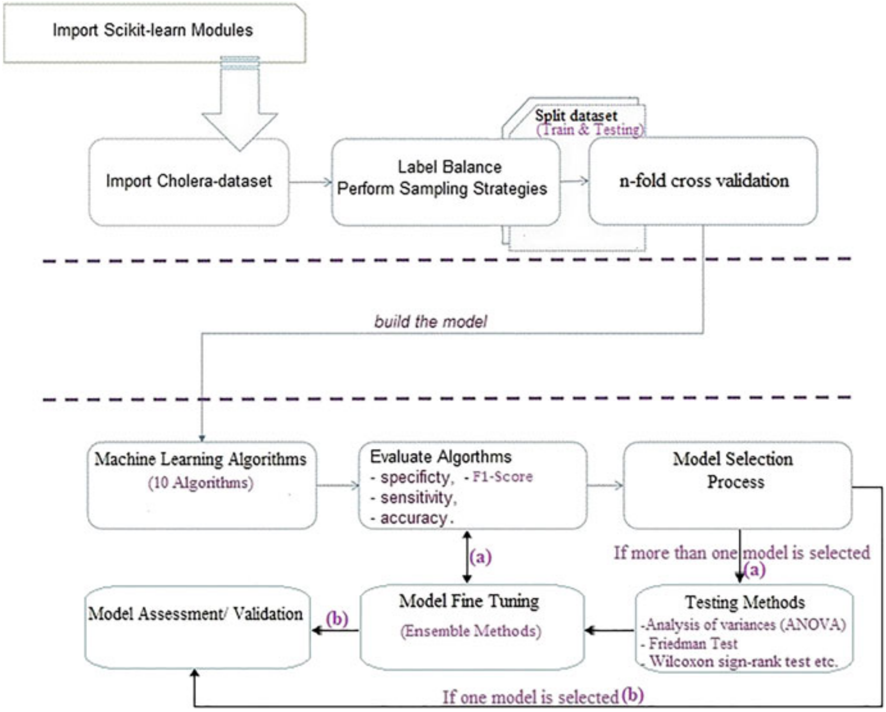

Fig. 5 Development-procedure for development of ARPM

Table 4 Results of F1-score, sensitivity, specificity and balanced-accuracy metrics for ten algorithms

SN	Model name	Performance (F1 Score)	Sensitivity	Balanced accuracy
1.	XGBoost classifier	0.210	0.994	0.558
2.	Gradient boosting classifier	0.304	0.995	0.590
3.	Random Forest classifier	0.610	0.982	0.740
4.	Bagging classifier	0.613	0.994	0.741
5.	MLP classifier	0.346	0.988	0.608
6.	K-NN	0.320	0.989	0.597
7.	Decision tree classifier	0.456	0.985	0.656
8.	Supper vector classifier	0.090	0.999	0.523
9.	ExtraTree classifier	0.590	0.996	0.719
10.	Logistic regression classifier	0.057	0.989	0.513

Table 5 Results of FM test rank for the best 10 algorithms

Model name	XGBoost	GB	RF	Bagging	MLP	K-NN	DT	SVM	ET	LR
FM results	5	4	2	1	6	7	8	9	3	10

Table 6 Results of F1-score, sensitivity, specificity and balanced-accuracy metrics for the best three algorithms

SN	Model name	Performance (F1 Score)	Sensitivity	Balanced accuracy
1.	RF classifier	0.610	0.982	0.740
2.	Bagging classifier	0.613	0.994	0.741
3.	ExtraTree classifier	0.590	0.996	0.719

Table 7 Results of F1-Score, sensitivity, specificity and balanced-accuracy metrics for voting classifier

SN	Model name	Performance (F1 Score)	Sensitivity	Balanced accuracy
1.	Voting classifier	0.651	0.965	0.785

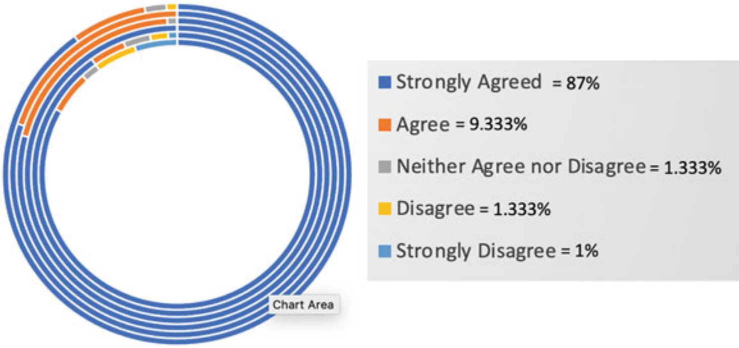

Fig. 6 Validation results of the proposed measures

Neither Agreed nor Disagreed, 1% Disagreed, and 1% Strongly Disagreed as shown in Fig. 6. Whereas for the Section A part of the questionnaire, the results assisted in the development of the conceptual framework, getting clear understanding of the challenges from the participants and also, some of the results are shown in Table 8. The results for question 1–4 were captured in Table 2.

5 Conclusion and Future Work

To conclude, it should be noted that in the past couple of decades, development in terms of computer processing, power, and availability of affordable memory has been growing exponentially (Kingdom, 1998). Hence, the need for traditional statistical modeling is losing momentum since the machine can handle large amounts of data in terms of storage and processing without the need to reduce them through the use of mathematical techniques (Kleinstreuer & Xu, 2016). This idea has given

Table 8 Results of section A–Social-economic profile of the respondent in the questionnaire

Questions	Section A–Social-economic profile of the respondent			Description of the Results on each question
Question 5: Choose the most used techniques for timely prediction of cholera epidemics?	(a)	(b)	(c)	70% of the participants selected item (c), meaning that the most existing techniques/ initiatives for timely prediction of cholera epidemics are non-ICT based.
	1%	29%	70%	
Question 6: Is there any linkage between the occurrence of choler disease with the environmental factors?	(a)	(b)	(c)	86% of the participants are aware that there is a linkage between the occurrence of choler disease with the environmental factors such as weather changes.
	86%	10%	4%	
Question 7: Are ML models capable of integrating many factors?	(a)	(b)	(c)	86% of the participants are aware that the ML models capable of integrating many factors
	75%	5%	20%	

the power to the rise of ML techniques and the need to foster collaboration among mathematics, statistics, and computer science communities. Such collaboration could spur real and meaningful progress in tackling big data challenges in our health sectors and others (Nongxa, 2017). In addition, with AI techniques, it is possible to quickly and automatically produce models that can analyze bigger, more complex data and deliver faster, more accurate results even on a very large scale (Jordan & Mitchell, 2015). This paper, therefore, presents a brief review of Cholera epidemic models, further explores the capacity ML techniques, and lastly, develop a model following the ARPM conceptual framework, and the model development approach or procedures towards complementing the limitations and complexity of existing Cholera epidemic models. The study recommends a review of healthcare systems in Tanzania in order to facilitate the collection of quality data. Lastly, further studies should enhance the security features of ML models.

Appendix

Focus Group Discussion and Interviewer-Administered Questionnaire

I am Dr. Judith Leo, a Lecturer at the Nelson Mandela African Institution of Science and Technology (NM-AIST)—Arusha. I am currently doing a research on proposing measures to overcome challenges in the existing initiative of timely Cholera prediction by proposing ARPM and its development procedure through the use of ML techniques. This questionnaire is aimed at assessing the perspectives of healthcare, environmental workers, cholera and diarrhea patients, ICT, Maths and ML experts on its feasibility, user acceptance, complexity, and impact of using an ARPM to enhance timely cholera epidemics analysis and prediction in Tanzania. The following are some of the sample questions.

Questionnaire Number:
Date:
Name of the working location:
A. Social-Economic Profile of the Respondent

1. Full name of the respondent: . . . .
2. Gender *(Mark only one)*
   (a) Male
   (b) Female
3. Age *(Mark only one)*
   (a) Below 19 years
   (b) 19 up to 30 years
   (c) Above 30 years
4. What is your level of education?
5. Choose techniques/initiatives that have been done to timely predict Cholera epidemics?
   (a) ICT-based techniques through the use of Machine learning techniques
   (b) ICT-based techniques through the use of non-Machine learning techniques such as Mathematics, mobile app etc.
   (c) Non-ICT-based techniques such as policies and guidelines
6. Is there any linkage between the occurrence and transmission of Cholera disease with the environmental factors?
   (a) Yes; there is a linkage.
   (b) No; there is no linkage.
   (c) None of the above.
7. Are ML models capable of integrating many factors? (*Tick one–either Yes or No*).
   (a) Yes.
   (b) No.
   (c) None of the above.

B. Information about the Validation of the Proposed Measures (Please Answer Questions that Concerns you as Regards to Expert Levels)

Please indicate the level of agreement by ticking in the box, corresponding to the row and column					
	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I found it easy to learn and follow the development procedure of ARPM					
The proposed ARPM can solve the existing challenges of big data and timely prediction					
It is very important to integrate environmental factors in the prediction of cholera epidemics					
The proposed ARPM and its procedure is useful towards the development and implementation of ML cholera epidemic models					
I would prefer these techniques (ARPM and its procedure) in the development of prediction models for different diseases					
The proposed measures and developed model can be easily applied in the developing countries' settings towards complementing the limitations and complexity of existing cholera epidemic models.					

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Structured and Targeted Communication as an Enabler for Sustainable Data Science Projects

Felix Kruse, René Kessler, and Jan-Hendrik Witte

Abstract In the modern, highly digitized world, the use of data plays an increasingly important role. In order to extract information from data and create value, data products must be created and developed. In the field of sustainability, for example, in the smart city context, it can also be observed that Data Science is becoming more and more central. There is a need for data scientists and stakeholders to actively collaborate to create valuable data products based primarily on the data. In general, it is the job of data scientists to develop the data product and the job of decision-makers to use the data product to support decisions. Therefore, effective communication between data scientists and stakeholders is a crucial success factor in data science projects. Communication problems can occur at the interface between data scientists and stakeholders. To date, there is no approach to implement and facilitate efficient communication processes between data scientists and stakeholders. This chapter presents an approach for efficient communication processes between stakeholders and data scientists called the Data Product Profile. The concept was developed based on existing literature and expert interviews and evaluated with practitioners.

Keywords Data science · Data product profile · Stakeholder communication · Sustainability · Smart cities

1 Introduction

To facilitate a more structured communication between data scientists and stakeholders, data products have to be the central result of every single data analysis process. Data products should support the achievement of goals, for example, from the corporate or the environmental context. Data products describe products that are

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based on data and provide a benefit to decision-makers or users. Therefore, the result of data analysis can also be described as a data product. In companies, the data product can be used for decision support in different forms, such as a report, a service for end-consumers, or simply as an analysis model deployed in the production. However, not only in companies can data products be used for decision support, but also in the course of sustainability-relevant projects, numerous decisions have to be made, which should be supported as targeted as possible. For example, Data Science is a core component of Smart City concepts (Moustaka et al., 2019). On the other hand, the data product serves as an intermediate between data scientists and stakeholders (Anderson, 2015b; Patil, 2012; Provost & Fawcett, 2013a).

Despite the availability of vast amounts of raw data and various analytical tools to process it, most decisions are based on specific individual factors. According to surveys conducted by Anderson (2015b) and BARC (2017) around 58% of companies' decisions are made based on personal feelings, intuitions, or experiences, rather than being explicitly derived from corresponding data. So decisions are not yet data-driven; on the other hand, several studies have shown that data-driven decision culture can provide a significant advantage over competitors or simply lead to higher quality decisions (McElheran & Brynjolfsson, 2016; Brynjolfsson & McElheran, 2016; Kessler et al., 2019).

Realizing data products will open the door for data science experts and domain knowledge experts, such as stakeholders. What applies to companies, in this case, can also be transferred to projects and applications of Data Science in the field of sustainability, since, for example, in the realization of Smart Cities, data is at the center, and the Data Scientist has a supporting role (cite). In particular, the collaboration between Data Scientists and users, i.e., citizens, is emphasized in the literature. Thus, citizen participation, in particular, is of fundamental importance, and the Data Scientist must not only have analytical skills but, above all, be able to communicate results in an appropriate form (De Obeso-Orendain et al., 2016). For example, numerous stakeholders are involved in the realization of smart cities: According to Van der Hoogen et al. (2019, 2020), these stakeholders can be classified into the roles Enabler, Provider, Utiliser, and User (Van der Hoogen et al., 2019; Van der Hoogen et al., 2020). It should be noted that, in addition, the actors in these roles can differ significantly concerning the goals pursued (Van der Hoogen et al., 2019, 2020). Whenever different actors or groups work together in a data science project, communication must inevitably be maintained and supported to achieve the goals. In this way, all stakeholders will benefit from the mechanisms of data science and move towards data-driven decision processes. The data product should be created in collaboration between data scientists, decision-makers, and other associated stakeholders (Kowalczyk & Buxmann, 2014; Provost & Fawcett, 2013a).

According to the work of Provost and Fawcett (2013a), there are explicit dependencies between data-driven decisions and data science. The starting point is a data processing and data engineering. These steps serve as the basis for data science and analytical processes. Regardless of the structure of these dependencies, it remains unclear how exactly an interaction between data-driven decisions and data science could be facilitated. Up to now, most companies have performed a descriptive analysis in the form of reports. However, most of them do not fulfill the requirements of users or are not explicitly used by decision-makers, and therefore no value is created (Anderson, 2015a). As the demand for predictive and prescriptive analysis increases, the need for data scientists in companies is growing. Although one of the essential skill areas of data scientists is communication, the interaction and communication between data scientists and stakeholders are not formally described nor adequately addressed (Davenport & Patil, 2012; Schmid & Baars, 2016).

In other words, when a data science process based on the widespread *Cross Industry Standard Process for Data Mining (CRISP-DM)* (Wirth & Hipp, 2000) is implemented, it remains unclear how the CRISP-DM process could be adjusted to be able to reflect all information needs of decision-makers. Currently, within the CRISP-DM model, the role of the decision-maker is summarized in the *Business Understanding* step. It is the first step of the analytical process, and it is not sufficient to only integrate domain knowledge at this stage. Decision-makers and stakeholders may also play a valuable role in more advanced steps.

For instance, according to Kowalczyk and Buxmann (2014), to have a successfully deployed data-driven decision process, an interaction between decision-makers, stakeholders, and data scientists should be facilitated and supported by heterogeneous methodology. This is necessary to reach a common understanding of any given problem and its solution from both sides, the ones performing data analysis and obtaining insights and the ones using these insights to make decisions and, therefore, create corporate value.

To bridge the gap between data scientists, decision-makers, and stakeholders, we introduce the Data Product Profile (DPP) as a method for communication optimization. The DPP interlinks both data science and data-driven decision processes. According to Loukides (2010); Patil (2012) and Stockinger and Stadelmann (2014), the data product is defined as follows: "*A data product is the central result of the analysis process of data science. The data product supports the achievement of business goals. (...) The main objective is for the data product to generate added value from the analysis of the data.*" It allows decision-makers and other stakeholders to participate more actively during essential steps of a data analysis process without a deeper understanding of data mining and machine learning techniques.

Encouraging decision-makers and other relevant stakeholders to participate in the data analysis process will improve quality results. They have a lot to offer in terms of domain expertise. In addition to the quality of obtained results, such an approach will also increase the acceptance rate of the resulting analytical model, as the stakeholders will be a part of its creation. Taking part in generating such a model, stakeholders will be more confident about the obtained results. This will increase the probability of integrating the results into the decision-making process.

To determine the requirements for the DPP, a systematic literature review has been carried out. After the requirements had been determined, the DPP was developed. The decision process and the CRISP-DM were combined to meet the requirements, and the DPP as a process-supporting artifact was developed. The last step includes the evaluation of the developed artifacts in the frame of five case studies and two workshops in an SDAX[1] company.

2 Towards Optimization of Communication in Data Science Projects

In this section, the development of the Data Product Profile (DPP) is described. The DPP is defined as an instrument to create a shared knowledge base of the participating stakeholders and a structured approach for the CRISP-DM. First, the current state of research is presented. Then the conducted requirements analysis is described. Finally, the developed DPP is described as part of the data-driven decision process.

The contribution of Kowalczyk and Buxmann (2014) represents an actual state of business intelligence and data-science-based decision-making processes. More specifically, the authors describe the relationship between data science and data-driven decision-making processes than Provost and Fawcett (2013a). A key finding of the paper is that data-driven decision-making processes should not be based solely on technological aspects of algorithms but also on the understanding gap between data scientists and decision-makers (Kowalczyk & Buxmann, 2014). The contribution of Elgendy and Elragal (2016) has a more technical view than the contributions of Provost and Fawcett (2013a) and Kowalczyk and Buxmann (2014). They present their "*Big Data, Analytics, and Decisions*" (B-DAD) framework, which links the decision-making process and the analytical process with all the technologies. (Elgendy & Elragal, 2016). The thesis of Cato (2016) focuses on its work on big data systems, which in turn often have the goal to enable and promote data-driven decisions. Requirements for the concept of using data science to support the data-driven decision-making process can be derived from the thesis Cato (2016). The contributions highlight some of the obstacles to using data science to support the data-driven decision-making process. However, no scientific publication provides a guide or concept on how the interaction between a data scientist, decision-maker, and stakeholder should occur.

The contributions of Provost and Fawcett (2013a); Kowalczyk and Buxmann (2014); Elgendy and Elragal (2016); and Cato (2016) show the organizational and technical research directions in the field of data science and data-driven decision-making. The publication of Provost and Fawcett (2013a) shows the relationship between data science and decision-making (see Fig. 1). Data engineering and processing, both dedicated to saving and processing large datasets, are mandatory to start analytical processes. Analytical processes will use this data to improve business decisions, which is the major interest of the business.

[1] The SDAX is a German stock market index consisting of 70 small and medium-sized companies

Fig. 1 Relationship between data science and data-driven decision-making based on Provost and Fawcett (2013a, p. 54)

Table 1 Search strategy and parameter

Databases	Search words
GVK plus	Science direct, the ACM digital library, advanced analytics, analytics, big data, Oldenburgisches Regionales Bibliotheks–big data systems, business analytics, data und Informationssystem (ORBIS) and driven, data-driven decision-making process, data product, data science, decision, decision-making, decision-making process, decision support, decision support system

2.1 Requirements

The requirements for the DPP should be determined with the help of a qualitative content analysis according to the approach of Watson and Webster (2002). Conducting the qualitative content analysis, the following research question will be answered:

What are the requirements for the use of data science concerning the decision-making process?

Table 1 lists the databases and search terms used for literature research. At least one of the search words appears in the contribution.

The review revealed 70 possibly relevant articles. After screening the abstracts and summaries and conducting a forward and backward search, 14 relevant articles remained. Based on these 14 articles, the requirements were determined by inductive category formation, according to Mayring (2015). In the course of inductive category formation, the analyzed material was reduced to the essentials and summarized. Seven relevant requirements were extracted that must be addressed to support the decision-making process with data science methods (see Table 2).

2.2 Bridging the Communication Gap with the Data Product Profile (DPP)

In this section, the DPP is described, which takes into account the previously determined requirements. In order to operationalize the DPP, it should be integrated into an analytical process. For this, the CRISP-DM was chosen as the most common and established analytic process in companies (Brown, 2016).

To interconnect data science and the data-driven decision, the data product is placed between them as an output of data science and an input of the data-driven

Table 2 Overview of the requirements sorted by number of entries

Code	Requirement	Number	Article ID
OR1	Support communication and cooperation between data scientists, decision-makers and stakeholders	11	Cato (2016); Davenport (2012); Gross and Thomsen (2016); Guerra and Borne (2016); Howard et al. (2012); Kim (2016); Kowalczyk and Buxmann (2014); Miller and Mork (2013); Patil (2012); Provost and Fawcett (2013b); Provost and Fawcett (2013a); Schmarzo (2016)
OR2	Focus on company's benefits	8	Davenport (2012); Guerra and Borne (2016); Kim (2016); Kowalczyk and Buxmann (2014); Patil (2012); Provost and Fawcett (2013b); Provost and Fawcett (2013a); Schmarzo (2016)
OR3	Analytical approaches and decision process combined	6	Davenport (2012); Elgendy and Elragal (2016); Howard et al. (2012); Miller and Mork (2013); Provost and Fawcett (2013a); Schmarzo (2016)
OR4	Thinking in data products	5	Cato (2016); Guerra and Borne (2016); Howard et al. (2012); Patil (2012); Schmarzo (2016)
OR5	Data product as an alternative for action in a decision-making process	1	Schmarzo (2016)
OR6	Secure data product insights	1	Schmarzo (2016)
OR7	Identify data product stakeholders	1	Schmarzo (2016)

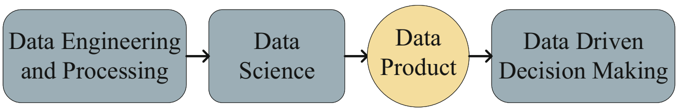

Fig. 2 Relationship between data science, data-driven decision-making and data product–own illustration based on Provost and Fawcett (2013a, p. 54)

decision-making process (OR5) (see Fig. 2). By positioning it between both domains, the importance of data is to be promoted as an essential business resource (OR5).

By combining the CRISP-DM with the classic decision-making process, a data-driven decision-making process emerges (see Fig. 3). This combination fulfills the requirement OR1. The decision process can be combined with the CRISP-DM. Both have an iterative nature and have parallels in their process steps. The data-driven decision-making process should also be iterative.

The process depicted in Fig. 3 is to be carried out by a data science team. In this team, data engineers, data scientists and decision-makers (business owners and project sponsors) work together to develop a suitable data product. In this process, communication and collaborative work should be ensured (OR11). To ensure this, the DPP will be developed, which will be integrated into the data-driven decision

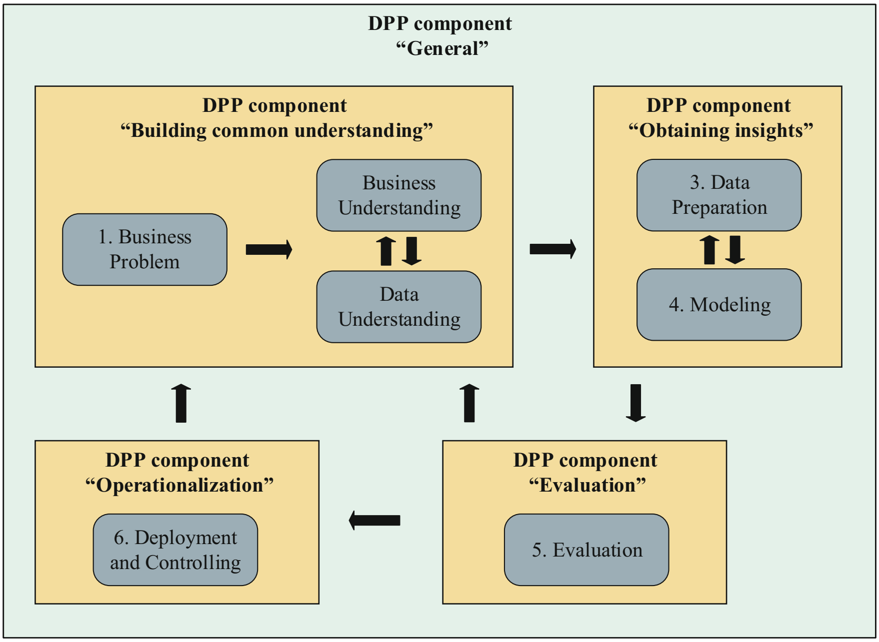

Fig. 3 DPP in the data-driven decision-making process–own illustration

process (see Fig. 3). The DPP is intended to support the communication and cooperation of the team members in all process steps. It provides a guideline for structurally processing all essential topics in the individual process steps and for building a common understanding. The following process steps should only be started once all relevant topics of the previous process step have been completed. This is intended to promote a structured transition of the data-driven decision-making process.

The DPP serves as a supporting tool in the data-driven decision-making process. Three existing concepts were used for the content design of the DPP. Because a data product can be seen as a kind of start-up idea, the content from the Business Model Canvas, a widely used start-up support framework, was utilized. The Drivetrain Approach Framework influenced the design of the DPP content, as it represents a rough data product development process. Moreover, the third existing concept used is the CRISP-DM (Howard et al. 2012; Osterwalder and Pigneur 2013, pp. 12–14).

The DPP should create the following added value during the process:

- The participation of all data science team members in creating the Data Products reduces the resistance to data-driven decision-making processes. It promotes their acceptance at the same time. The DPP is the central medium to support all involved in their communication and collaboration (OR1).
- Participation and the collaborative development of the DPP lead to an exchange of knowledge between the team members. This knowledge exchange is intended

to foster the team members' data-analytic thinking. Data scientists, decision-makers, and stakeholders should learn from each other.

- An often complex analytical project gets a structured guide through the DPP to master the complexity.
- There is a central place for securing knowledge about the data product (OR6).
- A joint unified knowledge base is built within the data science team, which is always visible through the DPP and shared with other employees. The knowledge base can also be used in future projects.

The DPP should support the individual process steps from the developed data-driven decision process (see Fig. 3), so that it can be executed in a structured manner. The process is divided into five components, which can be assigned to the process steps (see Fig. 3). Component *building common understanding* should support the process steps business problem, business understanding and data understanding. If this component of the DPP is sufficiently processed, component *obtaining insights* should support the process steps of data preparation and modeling. After component *obtaining insights* of the DPP has been completed, component *evaluation* for the evaluation process step and component *operationalization* for the process step deployment and controlling follow. Component *general* contains topics such as tasks, efforts and show stoppers and should be available in addition to the other components in each process step.

2.2.1 Component Building Common Understanding

The business problem is the trigger for the start of the data-driven decision-making process. The DPP is intended to help with the initial understanding of the data, the definition of the company benefit and the decision to be supported. The contents to be filled in for the business and data understanding process steps in the DPP are described below:

Data product name: The data product to be created should have a short descriptive name. This name is used for communication within the analytical project or the data-driven decision in the company.

Stakeholder: Under the item stakeholders, all employees or company divisions that are important for the creation and operationalization of the data product should be recorded (OA7[2]). In addition, the employee's or company divisions' tasks should be briefly described to record the responsibilities for the entire project.

Product owner: At least one business unit should be defined as the product owner of the data product. The product owner is the decisive instance when it comes to conflicts of interest between stakeholders and decides on changes and change requests for the data product.

[2] OA7: Identify Data Product Stakeholder

Description of the business case: The business case should provide a common objective for all stakeholders involved. Critical technical terms should be described and recorded so that uniform domain knowledge is built up in the Data Science team.

Corporate goals and benefits: This aspect in the DPP is to implement requirement OA13.[3] The company goals and benefits should be described, which are pursued with the data product.

Decision to be supported: Once the general business case has been described, the concrete decision to be supported or improved by the data product is defined.

Environmental conditions: The environmental conditions can influence the result of the data product or another alternative course of action. These states cannot be directly influenced. This point is intended to make the potential reasons that could influence the success of the decision or lead to the failure of the project transparent to all team members.

Further action alternatives: At this point, the current alternative course of action for the decision to be supported is described. If there is currently no alternative course of action, potential alternatives should be described. With these action alternatives, the data product can be compared concerning target fulfillment.

Operationalization: Already in this early phase of the analytical project, the data science team should decide how the data product is operationalized and which tasks are necessary for this. For example, suppose operationalization is not feasible in the near future since time-consuming preliminary work is required. In that case, the development of the data product should be stopped for the time being.

Data(sources): The data science team should describe the potentially relevant data and data sources. The most critical presumed data for the data product should be roughly described. A common understanding of data is built by involving the entire data science team, which can be helpful in further projects or lead to new project ideas.

Analytical methods to be used: The potentially applicable analytical methods for developing the data product. For example, decision trees, clustering methods or neural networks. By discussing the potentially applicable analytical methods with the entire data science team, know-how in data science analytics is built up, and data analytic thinking is promoted. The knowledge gained about analytics can, in turn, help in further projects or promote new project ideas.

Description of target values for measuring success: This section of the data product fact sheet describes the target values for measuring success. These can be, for example, quantitative monetary target values, such as the increase of annual sales in a company division, or qualitative target values, such as the increase in customer satisfaction.

Procedure for measuring target values: This point describes the procedure for measuring the target values. For example, these could be measured using existing

[3] OA13: Focus on company's benefits

KPIs. If the KPIs do not yet exist, it should be clarified and described how the key performance indicators (KPIs) could be measured.

Required data/data sources for measuring the target values: If the description of the procedure for measuring the target values reveals that decisive data sources or data are not yet available, these should be documented at this point. In addition, responsibilities should be clarified as to how the data sources are provided to measure the target values.

2.2.2 Component Obtaining Insights

The 2 component of the DPP is intended to support the process steps of data preparation and modeling. Once all essential contents of component 1 of the DPP have been populated, the data product can be developed in these two process steps. The contents that are to be documented in the DPP during these process steps are described below:

Analytical method: Under this point, the analytical method used, such as a decision tree, logistic regression or a neural network, should be defined.

Description of the databases used: The data basis is described here. It will list which data sources are used and how large the data basis is. If a sample is used, the generation of the sample and the sample size should be documented. Also, other special features of the data basis could be documented, such as which observation period and training period contains.

Description of data preparation: This item in the data product fact sheet is intended to describe data preparation. This includes, for example, the granularity of the data and the granularity with which the data is prepared. The calculation of new attributes from existing attributes should also be documented here. Description of the attributes used for the analytical procedure: At this point, the attributes used for the analytical procedure are described technically as well as their calculation logic. It is recommended to include a good extract of the data records to visualize the description of the attributes used.

Results of analytical procedures: Under this point, the results of all analytical procedures used are to be documented to evaluate them from a technical and functional point of view. For example, a gains chart, a confidence matrix or a historical in vivo evaluation can be displayed, described, and evaluated. In the end, the best data product should be selected.

Location of the source code: At this point, the location of the source code should be documented. For a deeper understanding, it can help to look directly into the source code and the source code comments.

Various data mining algorithms can offer the best possible solution for a data product. Often the data must be prepared for each algorithm differently. For this purpose, component 2 of the DPP should be completed for each analytical procedure implemented. However, the components “results of the analytical method” and “location of the source code” can be used for all the analytical methods used.

2.2.3 Component Evaluation

After the potential data products have been developed and component 2 of the DPP documented, evaluation can begin. The evaluation process step is supported by component 3. Important information for the evaluation has already been documented in component 1. The information on how and when the success of the data product should be measured is used here. Component 3 is described below:

Description of the evaluation: This point describes the evaluation method and the procedure for evaluating the data product. For example, a test campaign or an A/B test could be used as an evaluation method. In other action alternatives are available, these action alternatives should be compared.

Description of the framework conditions: At this point, the basic conditions of the evaluation should be documented. These include, for example, the methods used for evaluation. In the case of a test campaign or an A/B test, the contents of both means should be presented. Other framework conditions can refer to the restrictions of the evaluation environment, for example, if certain customers, regions, or machines are used.

Presentation and evaluation of the results: Under this point, the evaluation results are to be described and evaluated. Reference should be made to the defined target values in component 1.

2.2.4 Component Operationalization

The fourth component of the DPP supports the Deployment and Controlling process step. In this process step, the previously evaluated and selected data product is operationalized. The contents of component 4 are described below:

Description of operationalization: Under this point, the operationalization to be carried out is to be documented. The planned operationalization has already been documented in component 1 of the data product. The data-driven decision process can take a longer period so that the planned operationalization can deviate from the implemented one. If this deviation occurs, it should be documented explicitly. Controlling: The data product should be checked regularly, both technically and functional, to avoid deviations from the target. Under this point, a domain-oriented and technical data science team member and a time to review the data product should be defined.

2.2.5 Component General

The fifth component of the DPP is to be used throughout the entire analytical process. The component consists of general content that is relevant at all times during the process:

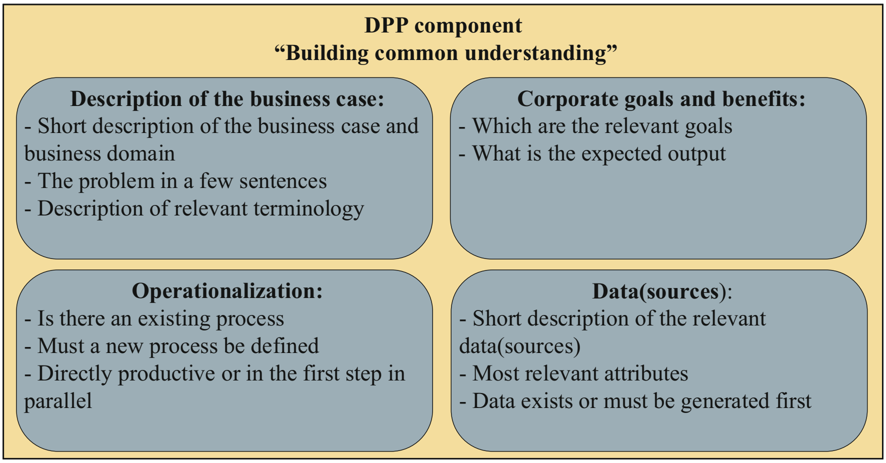

Fig. 4 Example of DPP guideline–own illustration

Tasks and effort for iteration: Under this point, the planned tasks and their input for the next iteration of the team members should be documented at each meeting of the data science team. These planned efforts are intended to promote the wait early approach. Due to the transparency of the costs for each iteration, a project can be stopped if the cost-benefit ratio is not economically sufficient.

Show stopper: In this part of the DPP, the upcoming show stoppers during the project will be documented. The show stopper should be described, a department or person responsible for the solution should be documented, and a time for resubmission of the project should be defined.

3 Evaluation

The evaluation of the DPP has been carried out using the qualitative methods case study and expert workshop (Wilde & Hess, 2006). The business partner provides both case studies and experts. Heterogenous departments of the partner company were involved in the case studies and workshops, such as the CRM team, a manufacturing team, the data science department, and the operational IT department. Employees from the operational level to strategic management were involved. The analytical infrastructure of the company consists of operational systems, which are combined in a classical business intelligence architecture with a Data Warehouse and an analytical layer consisting of the IBM SPSS Modeler and a Hadoop Cluster. The DPP is implemented in the form of a guideline to be used in the case studies. The guideline was used during the workshops to assist in filling out the DPP content for every component (see Sect 2.2) of the process. Exemplary content of the guideline for DPP component *building common understanding* is illustrated in Fig. 4.

In order to evaluate the practical suitability of the DPP, the DPP was used in an actual analytical project, and the project progress was analyzed via the resulting minutes of the meetings. The suitability cannot be thoroughly evaluated in the context of a case study and is also difficult to quantify with metrics. It was much more a matter of initially assessing the basic usability through the experience gained in the case study. The aim of the case study *"next best offer"* was to find the optimal moment to send an e-mail newsletter. Stakeholders were the data science team and the CRM department. The aim of the case study *"predictive maintenance"* was to predict the failure of production machines. Stakeholders were the data science team and the manufacturing machines department. The aim of case study *"segmentation"* was customer segmentation. Stakeholders were the data science team and the CRM department. The aim of the case study *"osf-tracking"* was to understand the customer behavior in a particular human-to-machine interaction context. Stakeholders were the data science team and the manufacturing machines department, and a consulting company. The aim of the case study *"heatmap"* was to create a heatmap about the usage of the software functions of some machines to improve the human–machine interaction. Stakeholders were the data science team and the manufacturing machines department.

The detailed analysis of the minutes of the meetings showed that the usage of the DPP generated heterogeneous value for corporate analytical projects. Employees from different departments and hierarchy levels engaged in the case studies. Some employees participated in several case studies, and some employees joined the process in later stages. This configuration made possible the verification of communication improvement in analytical processes. Structuring the analytical process into small subject areas resulted in more accessible, faster, more focused, and goal-oriented communication in complex analytical projects. For example, the first iteration of the component *building common understanding* took 2 h on average. The second iteration with the same employees did not take more than 1 h on average. So after 1 h, a common knowledge base and a common commitment about the focused business case, the analytical methodology, the data sources, the operationalization, and the success criteria were defined and documented. Later on, employees who joined the process could be easily integrated and updated with the information documented in the populated DPP. Further, employees shared their knowledge of data and analytical methods and were able to apply this in other case studies. The DPP was highlighted as a persistent and long-term knowledge base for analytical projects in the expert workshops. In summary, the DPP supports communication in analytical processes by reducing and structuring the complexity of communication processes.

4 Conclusion and Outlook

This paper discussed that data-driven decisions could be an advantage. Further evaluations, especially in the context of smart city projects, are conceivable. A data-driven decision must be based on a data product created jointly by decision-makers, stakeholders, and data scientists. At the same time, there is a communication gap between them, which has been confirmed by literature analysis. The DPP was developed to structure the analytical process and support communication processes between decision-makers, stakeholders, and data scientists. To reach this, the DPP is divided into five components that support the CRISP-DM process steps in terms of formal communication structure. The content of the DPP was created based on the CRISP-DM, the business model canvas and the drivetrain approach model. The DPP has been evaluated in practice using field experiments and qualitative methodology. The DPP was realized as a paper-based guideline that served as a basis for stakeholder meetings.

The DPP was successfully evaluated with a partner company using case study methods as well as expert workshops. The DPP structures the data-driven decision-making process that supports stakeholder communication and can thus lead to advantages through resulting data products for decision support.

Future research should address testing and evaluating the DPP in further case studies to further optimize its contents and recommendations. Also, a software tool should be implemented to prevent media breaks and ensure lean and efficient documentation. Moreover, quantitative analysis methods (definition and measurement of key performance indicators) should be applied to measure the impact of the usage of the DPP explicitly.

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Part V
ICT at the Service of Sustainable Agriculture

Network Analysis on Artificial Intelligence in Agriculture, a Bibliometric Review

Ahmed Karmaoui

Abstract Artificial Intelligence (AI) is a smart technology that can make decisions in real-time and low effort in many fields including agriculture. The AI technologies are changing agriculture based on sensors and cameras. This chapter reports on a literature review of the global collaboration and trends on AI in agriculture field (AIA). A number of 2143 documents were retrieved from 1984 to 2021 and processed using VOSviewer tool. The findings show an increasing trend in productivity on AIA, and 2013 was the starting point of an exponential evolution of the number of publications. Fu, Z. is the top author concerning the number of indexed publications followed by Ampatzidis. China Agricultural University, Chinese Academy of Science, and the University of Florida are the most influential affiliations. China ($n = 364$), the United States ($n = 317$), and India ($n = 311$) are the top three most productive countries on this topic. Research on AIA is turning to agricultural robots, Internet of things (IoT), big data, deep learning, and internet, etc. The keywords estimated using the software were classified based on field criteria into four levels: resources (groundwater), farms & agriculture, tools & techniques, and decision & management. This classification was used to develop a framework that can be considered as a decision-making tool to optimize agriculture using AI.

Keywords Global collaboration · VOSviewer · Bibliometric analysis · Research trends · Predictive analytics

1 Introduction

The key term artificial intelligence (AI) was used for the first time at Dartmouth College by John McCarthy in 1955 (Moor, 2006). AI refers to intelligent machines that can perform human tasks including reason, thought, and emotion. The

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associated terms are increasingly evolving and difficult to pin down by non-computer specialists (Jones et al., 2018). This AI has been explored in a wide range of studies in many fields, such as economic (Aghion et al., 2017), healthcare (Yu et al., 2018), biology (Webb, 2018), geosciences (Wang & Morra, 2021), mathematics (Gomez et al., 2020), parasitology (Das et al., 2013), and ecology & natural resource management (Humphries et al., 2018). This technology has given rise to specialized journals such as Annals of Mathematics and Artificial Intelligence; Artificial Intelligence in Geosciences; and conferences such as the International Conference on Hybrid Artificial Intelligence Systems, the AAAI Conference on Artificial Intelligence, and the International Conference on Machine Learning (ICML), and much more.

In environmental the field, climate change is among the most challenges that affect humanity. Coeckelbergh (2021) reported that AI technologies may contribute to deal with a large number of environmental problems and more particularly to mitigate climate change. In this context, machine learning (ML) is an AI technology that can be used to forecast weather and climate-related events like extreme events (higher than normal rainfall, hail events, heat waves) (Gaitán, 2020). AI technologies are promising tools that can make decisions in real-time and with low effort in productive sectors such as agriculture. This new perspective is changing agriculture in different agricultural life cycle steps.

Food security is a global concern to meet the increasing total population and human well-being. Traditional methods in agriculture are far from being able to meet the needs of this population. Automation has therefore become an urgent necessity in order to remedy this situation. In fact, AI technologies have helped in protecting crops from many issues such as food security, population growth, climate changes, and employment issues (Talaviya et al., 2020).

Climate change and human pressure is influencing traditional agriculture, which uses new technologies to collect and analyze data to take the appropriate decision about plant nutrition, irrigation, weed protection, phyto-health, yield, soil preparation, and harvesting, etc. AI has been increasing rapidly worldwide due to its role as a decision-making tool in several fields. In fact, it plays an important role in agriculture through many sub-domains and techniques such as Agriculture robots or Robotics and Autonomous Systems (RAS), the use of soil moisture and raindrop sensors, neutron moderation, weed control automated system, Pulse high voltage discharge method, and Unmanned Aeronautical Vehicles (UAVs) (Talaviya et al., 2020).

The current study represents a systematic review of the literature that uses a significant number of articles that provide useful information about the evolution of the topic. It gives also information on the journals, the authors the most influential, and the years of publications (Karmaoui, 2022). The main approaches, research domains are also considered. The relevance of this study lies in bringing together a large amount of information on this precise topic retrieved from thousands of indexed publications. Reviewing the literature, a number of publications on agriculture were found. Pandey et al. (2018) reviewed the relationship of agricultural credit with farmer distress. This study showed that farmer distress has drawn significant attention from researchers. The same study revealed that pesticide poisoning and farmer challenges are the issues the most studied. Raparelli and Bajocco (2019) explored the use of unmanned aerial vehicles in the agricultural and forestry field concluding that the former focused on crop status monitoring and precision farming. Rocchi et al. (2020) conducted a bibliometric analysis on Ecological Modernization Approach in Sustainable Agricultural Systems and revealed that agroecology, diversified farming systems, and agrobiodiversity were the most involved research content. However, Luo et al. (2020) explored the agricultural co-operatives in the western world identifying the main themes including governance structures of co-operatives, social and environmental performance of co-operatives, and trust and commitment in co-operatives. In this context, the relevance of AI in the agriculture sector is evident since institutions of research are increasingly aware of the importance of the associated applications. Many examples can be found in detecting plant nutrition and diseases, monitoring and controlling soil and water using sensors and cameras. These tools and technologies are usual to identify issues and solve problems particularly in the global south where the challenges used are more visible. Then, there is an urgent need to explore this field in developing countries.

This paper highlights the revolution in agriculture using AI instead of the traditional technics through a bibliometric analysis on some life cycle parts of agriculture using VOSviewer tool. It reviews global collaboration and trends on AI in the agriculture field. A number of 2143 documents were retrieved from 1984 to 2020 and processed.

2 Data and Methodology

This article reviews the topic of artificial intelligence in the agriculture (AIA) field using the knowledge diffusion approach (Liu et al., 2017). The research structure on AIA as the keyword was conducted using the Scopus database (Fig. 1). Scopus is the World's Largest Abstract and Citation Database of Scientific Literature (Schotten et al., 2017). Other prestigious databases can be used such as PubMed, Web of Science, and Crossref. In the current study, only the first 2000 from 2143 documents were retrieved from 1984 to 2020 and processed using VOSviewer tool. The first step was to acquire the information of the retrieved documents. Once the Scopus database is accessed, the related data was exported in the form of CSV excel including citation information, bibliographical information, abstract & keywords, funding details, i.e., funding text, number, acronym, and sponsor, and references.

The second step was the use of VOSviewer software. It was developed by Van Eck and Waltman (2010) in the Java programming language. The software uses a clustering algorithm that visualizes similarities using the occurrence method of keywords (Leydesdorff & Rafols, 2012). The exported data in the form of CSV is imported into the software to be analyzed. The most relevant keywords were considered and the counting method (analysis methods) was based on the co-occurrence of all keywords of the retrieved documents. The generated key terms are connected by co-occurrence, bibliographic coupling, co-authorship, co-citation links, or citation.

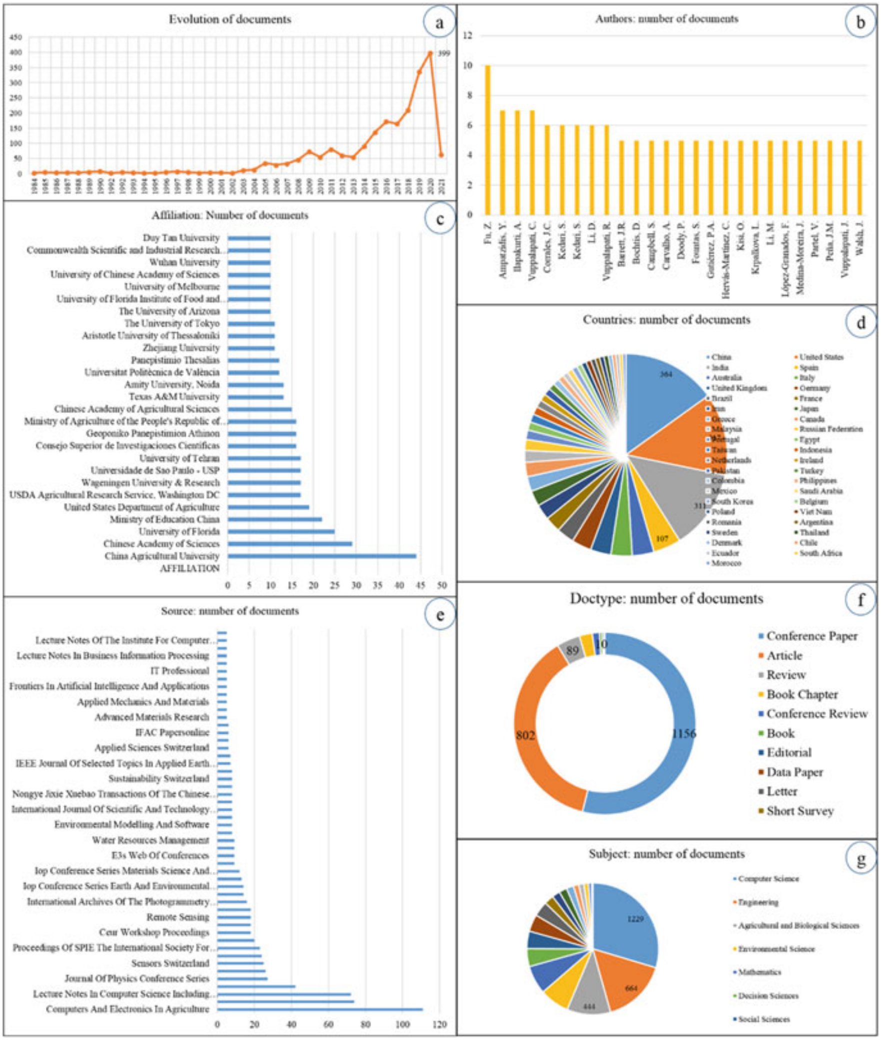

Fig. 1 The global collaboration and trends on AI in agriculture field using 2143 documents from 1984 to 2020

Based on VOSviewer, a network analysis was processed, which allows identifying the main clusters of key terms. Added to this clustering analysis, a manual new classification is proposed to develop the existing analysis methods of VOSviewer. Classification in clusters based on areas of research was done in new themes-based clusters, summarized also in a framework. This gives more specific and detailed information about the studied topic that can be used as a base to construct conceptual models in all research areas and used as a decision-making tool.

3 Results and Discussion

3.1 Global Collaboration and Trends on AIA

The global collaboration and trends on AI in the agriculture field using 2143 documents from 1984 to 2020 and VOSviewer tool were explored (Fig. 1). The findings show an increasing trend in productivity on AIA, where 2013 was the starting point of an exponential evolution of the number of publications (Fig. 1a). Fu, Z. is the top author concerning the number of indexed publications followed by Ampatzidis, Y., Ilapakurti, A., and Vuppalapati, C. (Fig. 1b). China Agricultural University, Chinese Academy of Sciences, and the University of Florida are the most influential affiliations on AIA (Fig. 1c). China ($n = 364$), United States ($n = 317$), and India ($n = 311$) are the top three most productive countries on this topic (Fig. 1d). Computers and Electronics in Agriculture ($n = 111$), Advances in Intelligent Systems and Computing ($n = 74$), and Lecture Notes in Computer Science Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics ($n = 72$) are the three top journals that published documents on AIA (Fig. 1e). For document types, conference paper ($n = 1156$), article ($n = 802$), and review ($n = 89$) are the most influential in the field of AIA (Fig. 1f), while Computer Science ($n = 1229$), Engineering ($n = 664$), and Agricultural and Biological Sciences ($n = 444$) are the top three subjects (Fig. 1g).

3.2 Network Visualization, Density, and Trends

Once the data was acquired from Scopus database, only the most relevant keywords were considered using VOSviewer software. The counting method was based on the co-occurrence of all keywords associated with the retrieved documents. A minimum number of occurrences of a key term was 20. Of the 15,137 key terms, 243 meet the threshold. For each of the 243 key terms, the total strength of the co-occurrence links with other key terms was estimated. The network analysis allowed identifying three main clusters (Fig. 2a). The red cluster gathers 96 key terms such as decision support system (s), water management, water supply, crop production, agricultural land, sustainable development, information system, and soils, etc. The second cluster has 74 items (green circles) like AI, agricultural robots, precision agriculture, internet of things (IoT), information management, global positioning system (GPS), cloud computing, and smart farming, etc. The following cluster comprises 68 blue circles including key terms such as learning systems, remote sensing, deep learning, learning algorithms, decision trees, computer vision, detection method, prediction, and classification of information, etc. (Fig. 2a). Density analysis (One of the kinds of VOSViewer visualizations in form of heat map) was generated to show the hottest keywords (Fig. 2b), while trends processes (tendencies) were performed to highlight the most topical key terms (current) related to AIA (Fig. 2c). To explore the most significant topical key terms linked to the search on AIA starting from the central key

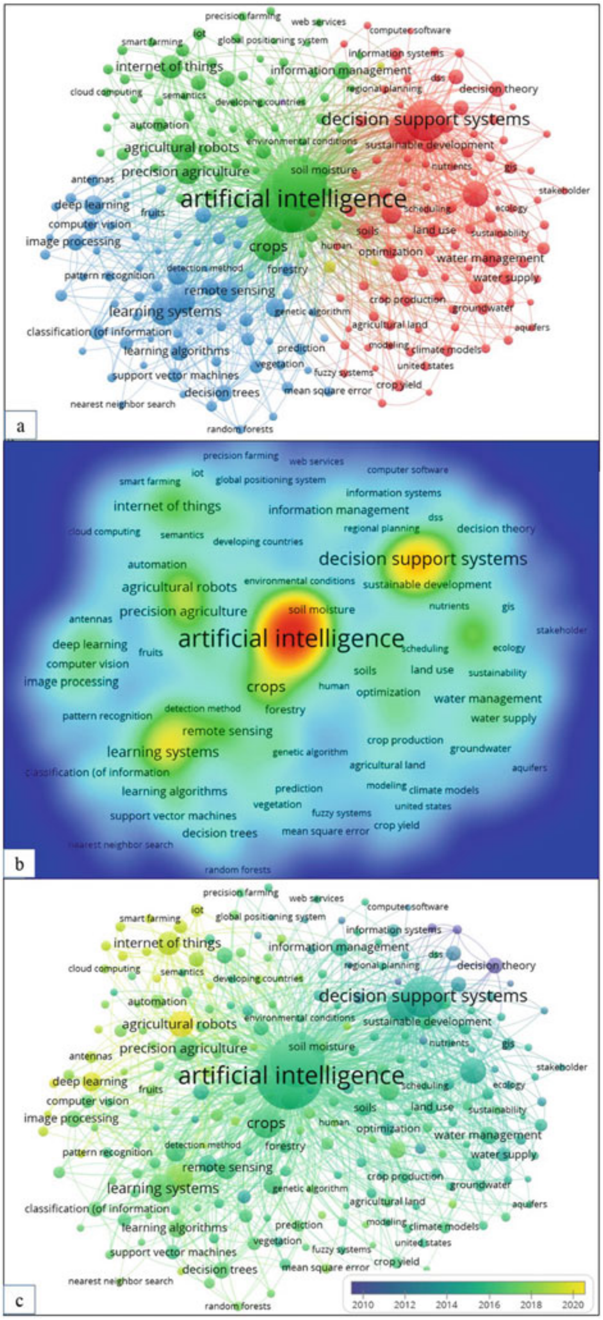

Fig. 2 Research structure on AI in agriculture field using documents from 1984 to 2020 and VOSviewer tool; (**a**), Network visualization; (**b**), density; and (**c**), trends

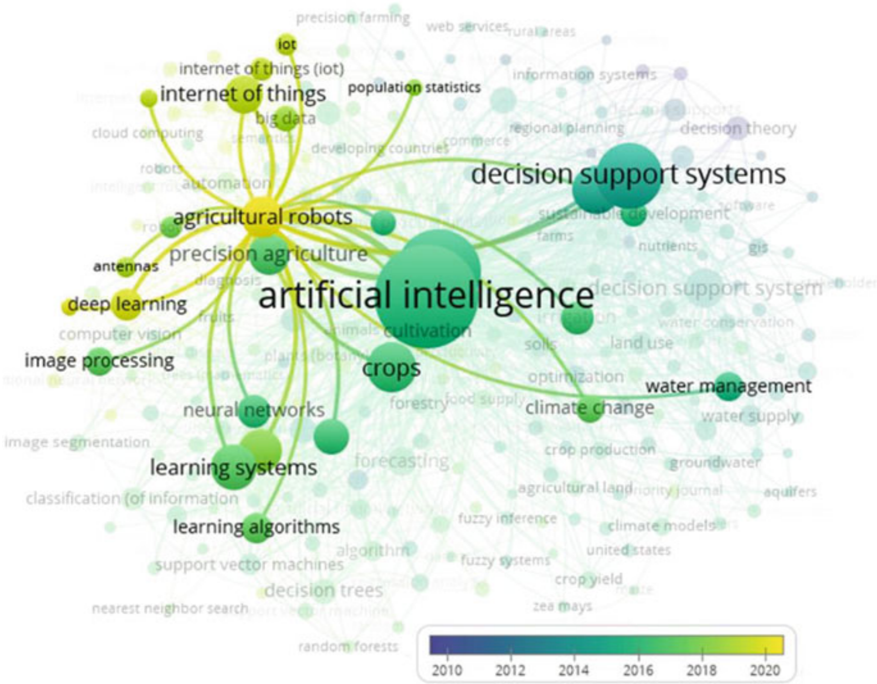

Fig. 3 Network visualization of topical keywords associated to the search on artificial intelligence in agricultural field highlighting the central key term "Agricultural robots"

term "agricultural robots," an example of network visualization was conducted (Fig. 3).

Figure 3 shows an example of network visualization of some topical key terms associated with the search on AIA starting from the central key term "Agricultural robots." Yellow circles represent the most recent items associated with the research key term. For example, when clicking on the keyword "agricultural robots," several links can be highlighted that associate this key term to the nearest key terms. These include the internet of things (IoT), big data, deep learning, and internet, etc.

The keywords estimated using the software were classified manually based on field criteria (Appendix 1). The following main key terms were identified: machine and machine learning, sensors, robots, algorithms, data, images, information, networks, computer, internet, systems, environment, water resources and management, soils, climate and climate change, economy, decision-making, agriculture production and systems, and land use. These categories were classified into four levels from the bottom to the top (structured in Fig. 4.) and are resources (groundwater), farms and agriculture, tools and techniques (including images, data, data analysis), and decision-management.

4 Resources

Water is the most important resource and condition for farming and is taken into account in AI technologies. The results show a high occurrence of this resource using the research key terms "AI in agriculture." These include water management (occurrence or o = 112, links or l = 1415), water supply (o = 76, l = 1006), water resources, (o = 72, l = 844), water quality (o = 62, l = 741), water conservation (o = 54, l = 678), groundwater (o = 51, l = 676), watersheds (o = 45, l = 598), rivers (o = 33, l = 462), water resource (o = 30, l = 457), groundwater resources (o = 31, l = 452), water pollution (o = 31, l = 368), aquifers (o = 24, l = 364), and reservoirs (water) (o = 20, l = 262). Soil is the second most important resource with higher occurrence. The bibliometric analysis recorded the following items: soils (o = 91, l = 994), soil moisture (o = 78, l = 827), soil surveys (o = 30, l = 349), soil Conservation (o = 21, l = 280).

In this level, climatic variables and climate change (climate change (o = 108, l = 1121), rain (o = 41, l = 443), drought (o = 34, l = 450), greenhouses (o = 32, l = 235), evapotranspiration (o = 27, l = 335), and runoff (o = 20, l = 281) are the factors that affect the quality and quantity of the two above-mentioned resources (water and soil). AI technologies have been used to protect crop yield from several factors such as climate changes and even population growth (Talaviya et al., 2020).

5 Farms and Agriculture

The Farms and Agriculture level includes the elements such as irrigation, plants, animals, seeds, fertilizers, and pesticides. The occurrence of key terms is organized as follows: irrigation (o = 206, l = 2398), cultivation (o = 130, l = 1337), agricultural productions (o = 301, l = 3106), animals (o = 59, 436), plants (botany) (o = 57, 558), fertilizers (o = 53, l = 596), fruits (o = 49, l = 355), maize (o = 47, l = 657), nutrients (o = 30, l = 335), weed control (o = 32, l = 309), seed (o = 32, l = 271), pesticides (o = 30, l = 242), nitrogen (o = 28, l = 325), and plant disease (o = 27, l = 232). Land use is another aspect that has a strong correlation with the bibliometric analysis that scored an occurrence of (o = 80, l = 974).

6 Tools and Techniques

The component of methods, technique, approaches, and disciplines include optimization (o = 80, l = 801) as the most frequent key term. This concept was considered as the third step of a decision-making process after the problem formulation, and problem modeling steps proposed by Koopialipoor and Noorbakhsh (2020). This last study reported several optimization models such as dynamic optimization,

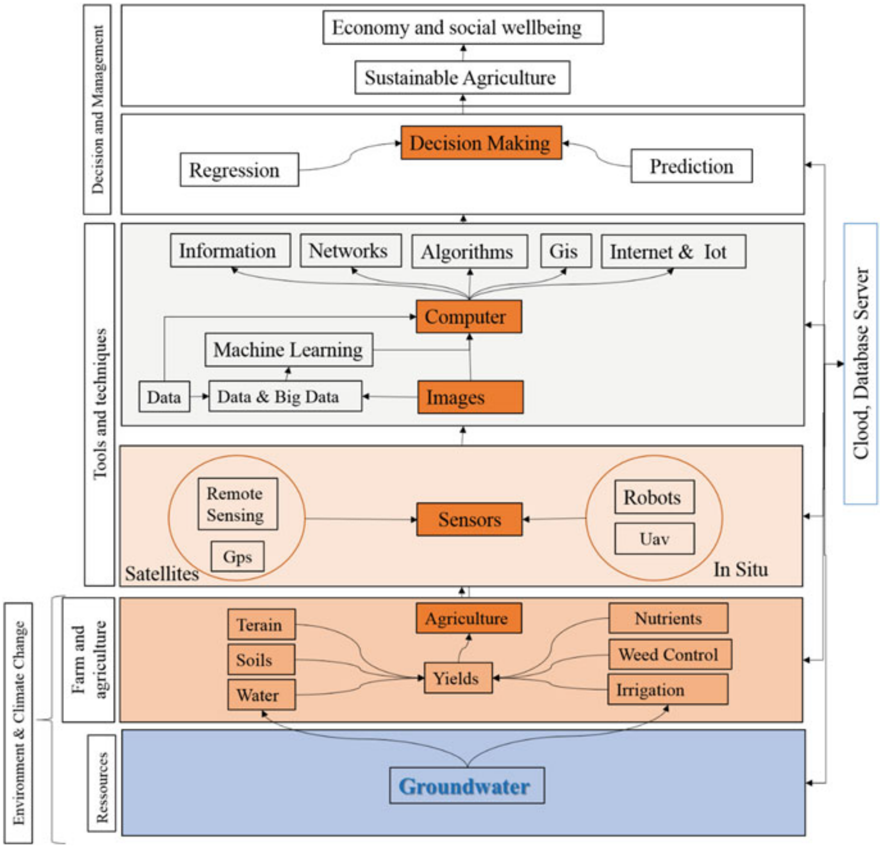

Fig. 4 Framework on the applications of artificial intelligence in the agriculture field

optimization under uncertainty, combinational optimization, non-analytic models constraint satisfaction, and mathematical programming. Models & modeling (o = 64, l = 774) are the following frequent concepts that are associated with the concept of optimization. The key term Economics (o = 53, l = 581) scored the third occurrence, which shows the influence of this aspect in AI. The studies investigating the economic aspects of AI and AI in economics are many (Chen, 2005; & Wagner, 2020a). Wagner (2020b) explored five economic patterns of AI including economics of AI networks, micro-division of labor, new factors of production, triangular agency relationships, and pattern from "homo economicus" to "machina economica." The results depict that climate models (o = 52, l = 588) constitute an interesting application in AI. Scoville et al. (2021) considered AI and climate change as trends highlighting their intersections. The key terms regression analysis (o = 51, l = 564), fuzzy logic (o = 53, l = 470), mean square error (o = 39, l = 456) were quantified as the most influential mathematical techniques used in AI. Feature extraction (o = 48, 434) and computer simulation (o = 45, l = 468) recorded very high occurrence in AIA field.

In regards to machine and machine learning themes, learning systems (o = 303, l = 3003), machine learning (o = 258, 2357), deep learning (o = 132, l = 1019), support vector machines (o = 121, l = 1315), agriculture machinery (o = 118, l = 1234) are the top five key terms. Machine learning and deep learning are components of AI. AI encompasses machine learning which in turn encompasses deep learning. Both of these two branches of AI use self-learning algorithms. In the agriculture field, Dokic et al. (2020) recorded a transition from machine learning algorithms to deep learning algorithms and found that in the past two decades, a trend of themes related to neural networks, deep learning, and machine learning.

Machine learning includes an important program called Support Vector Machines (SVM) that uses a classification machine-learning algorithm while agricultural machinery refers to vehicles, machines, and their economic and political supports that allow improving the yield in agriculture. Sharma et al. (2021) grouped machine learning applications into three categories detection (image interpretation, text & speech, abuse and fraud, human behavior and identity), prediction (classification, analysis, recommendations, and collective behavior), and generation (design, visual art, text, and musk). For the SVM, Camps-Valls et al. (2003) proposed to use it to develop crop cover classifiers using hyperspectral data (images) while Zolfaghari et al. (2013) explored the use of SVM for agriculture land use mapping with SAR data. Concerning the machine learning algorithm identified in the current chapter, Sharma et al. (2020) reported that the artificial neural network is the most widely used algorithm followed by regression, genetic algorithm, SVM, deep learning, and decision trees.

In regards to sensors component, the following key terms were identified: remote sensing (o = 178, l = 1755), wireless sensor networks (o = 90, l = 711), pattern recognition (o = 47, l = 342), sensors (o = 40, l = 316), sensor nodes (o = 36, l = 307), infrared devices (o = 24, l = 239), sensitivity analysis (o = 24, l = 224), and sensor networks (o = 23, 217). Remote sensing tools and AI have led to obtaining phenotypic information and use big data in order to predict and improve agricultural systems (Jung et al., 2021). Wireless Sensor Networks (WSNs) are among the technologies that changed completely in many fields and sectors including agriculture. Particularly, the observation and automation of phenotypic information of the farms, which allow controlling the threats and improving productivity. Buratti et al. (2009) cited the features of WSNs that are low cost and size of nodes, the capacity to be increased into the number of nodes in the network, low complexity, self-healing, energy efficiency, and self-organization. Robots-related keywords were found in the bibliometric analysis including agricultural robots (o = 247, l = 1792), robotics (o = 57, l = 350), unmanned aerial vehicles (UAV) (o = 44, l = 384), intelligent robots (o = 29, 176), and robots (o = 23, l = 143). Agricultural robots are conceived tools to conduct tasks in the agriculture field. Robots are very complex, including various sub-systems, which require to be integrated and synchronized to carry out tasks as a whole and transfer the necessary information (Bechar & Vigneault, 2016). UAVs and other robots agricultural field offer the possibility to monitor the farms at per-plant scale, which may reduce the quantity of pesticides and herbicides (Lottes et al., 2017).

For data key term, the findings show different concepts associated with the research on AIA fields such as data mining (o = 95, l = 757), big data (o = 85, l = 629), data handling (o = 53, l = 462), administrative data processing (o = 33, l = 406), data acquisition (o = 36, l = 342), data analytics (o = 31, l = 239), data set (o = 22, l = 284), and data processing (o = 21, l = 201). Data-mining techniques make it possible to analyze, correlate, and exploit big data. This tool is used in problem-solving and in identifying new opportunities in the agriculture field. According to Majumdar et al. (2017), data-mining techniques are the solution of the accurate yield estimation for the various crops involved in the planning.

Image (s) is another type of key term that was highlighted in this analysis comprising notions of image processing (o = 104, l = 839), image segmentation (o = 50, l = 413), satellite imagery (o = 37, l = 398), image classification (o = 34, l = 342), image analysis (o = 33, l = 312), and image enhancement (o = 23, l = 197).

In regards to the information category of key terms, the following concepts were recorded: geographic information system or GIS (o = 137, l = 1527), Information management (o = 113, l = 1040), classification of information (o = 89, 850), information systems (o = 60, l = 544), management information systems (o = 35, 428), information technology (o = 31, l = 208), information services (o = 20, l = 191), and global positioning system (o = 20, l = 182). These techniques are useful in collecting, visualizing, analyzing, and processing the collected data from the farms. To these techniques, network (s) key term provide essential tools to analyze and exploit collected data. The main key terms found are neural network (o = 176, l = 1561), artificial neural network (o = 87, l = 823), convolutional neural network (o = 72, 559), deep neural networks (30, 284), and network architecture (o = 25, l = 256). Computer and informatics, computer vision (o = 68, l = 533), automation (o = 74, l = 526), antennas (o = 51, l = 393), digital storage (o = 40, l = 394) scored both the higher occurrence and links. However, the Internet of things is the keyword the most cited in this category with a total occurrence of 364. Artificial Neural Network (ANN) is a deep learning algorithm used to predict the precise crop, which helps the farmers to collect the farm's parameters using sensors and the IoT (Priya & Yuvaraj, 2019).

7 Decision and Management

AI technologies are decision support systems that may assure sustainable development and meet the increasing population needs. The findings show a high occurrence of the key terms "decision support system (or tools)" (o = 1114, l = 10,983), decision-making (o = 323, l = 3139), decision trees (o = 101, l = 1144), decision theory (o = 90, l = 1013), and decision-making process (o = 24, l = 251). These tools have many objectives such as sustainable development (o = 97, l = 1006), monitoring (o = 44, l = 365), environmental impact (o = 43, l = 562), mapping (o = 41, l = 431), planning (o = 39, 469), environmental management (38, 443), environmental monitoring (36, 453), sustainability (o = 35, 417), regional planning (o = 30, l = 263), environmental conditions (o = 30, l = 258), and environmental protection (o = 21, l = 295). The economic and social aspects are also considered in AI technologies. The costs (o = 42, l = 367) and cost-effectiveness (o = 33, l = 336) scored the higher occurrence, followed by economic and social effects (o = 30, 366), commerce (o = 32, 263), profitability (o = 27, l = 296), energy utilization (o = 26, l = 204), efficiency (o = 22, l = 206), and energy efficiency (o = 22, l = 173). In fact, the AI technologies economize the overuse of water irrigation, herbicides, pesticides, workers, and preserve soil fertility, which increase the yield (Talaviya et al., 2020).

Figure 4 Summarizes a common framework (Structured based on field criteria and logical links) on AIA field based on the clustering of all keywords, their occurrences, and classification by themes. The above-mentioned four levels include the main components (Techniques, tools, systems, data, and information . . .) in the AIA field and the possible associations between levels and components

7.1 Co-authorship and Countries Analysis

Only the most relevant keywords were considered using co-authorship information to show the global collaboration. The counting method was based on the co-authorship analysis reported to the most influential countries in this study (Fig. 5). A minimum number of documents of a country was set to 20. Of 129 countries, 28 meet the threshold. For each of the 28 countries, the total strength of the co-authorship links with other countries was calculated. The countries with the greatest total link strength were selected that equal to 28 (Fig. 5, see also Appendix 2).

The closest study is the work of Ruiz-Real et al. (2020) entitled “A Look at the Past, Present and Future Research Trends of Artificial Intelligence in Agriculture.” While this study uses the same technique, our work considered aspects not explored in the first study such as doctypes, subjects, links, cluster analysis, and a much higher “minimum number of occurrences of a keyword” or thresholds selected (20). The trending countries in research on the topic, countries collaboration, density visualization option were also considered in the present study. What have not been done before are the extraction of all keywords (not only the author keywords), their classification on clusters based on co-occurrence, and by areas of research. This gives more specific and detailed information about the studied topic, which makes the current study a study that fills the gaps of the work of Ruiz-Real et al. (2020) (Table 1).

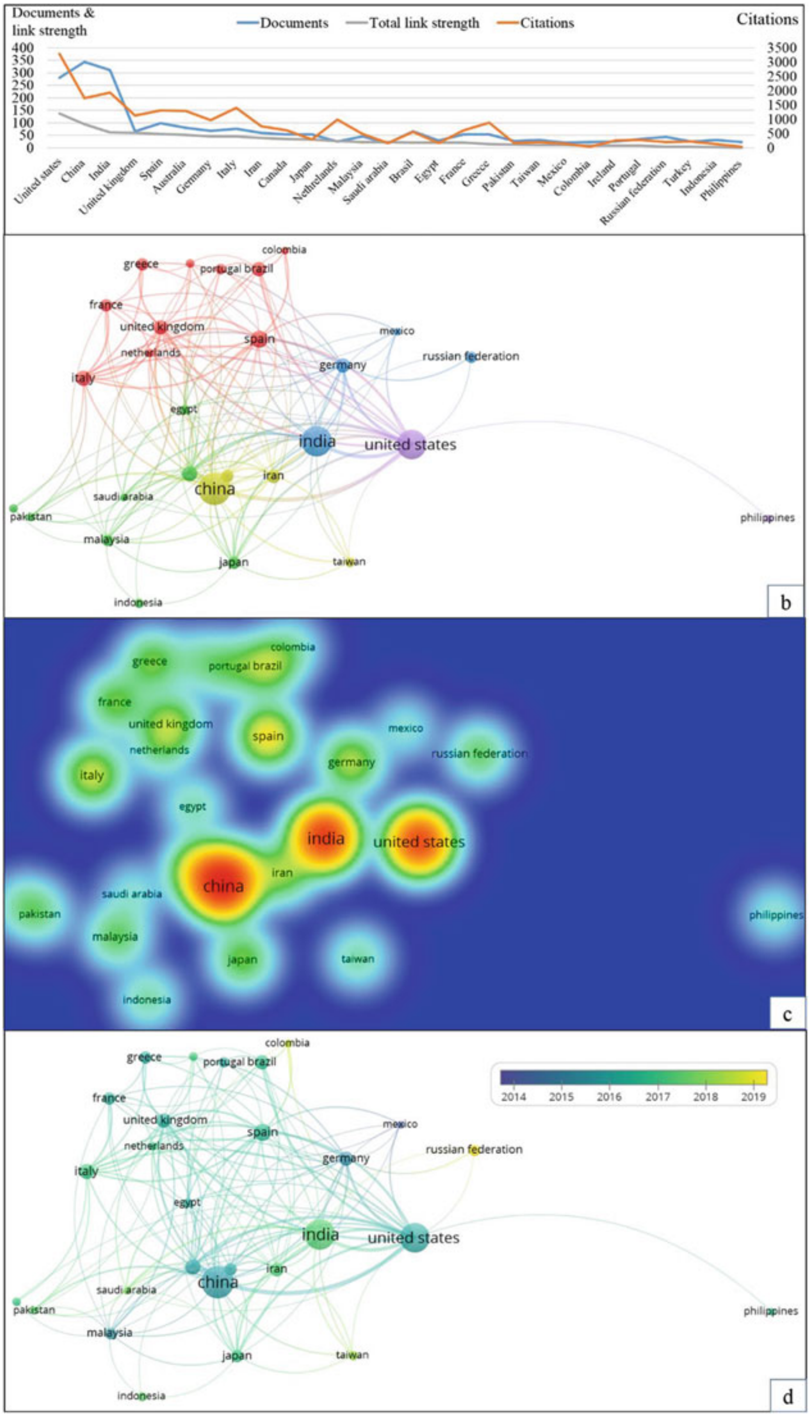

Fig. 5 Number of documents, citations, and total link strength of the most influential countries

Table 1 Comparison between the current study and the closest article

	Ruiz-Real et al. (2020)	Current study
Period	1976–2019	*1984–2021*
Software	VOSviewer	VOSviewer
Co-occurrence analysis	Authors' keywords	All keywords
Exported data	".txt"	CSV
Number of publications	Yes	Yes
Citations	Yes	Yes
Languages	Yes	No
Countries	Yes	Yes
Journals	Yes	Yes
Organizations publishing	Yes	No
Entities funding research	Yes	No
Trends	Yes	Yes
Doctypes	No	Yes
Subjects	No	Yes
Cluster analysis	No	Yes
Thresholds selected[a]	2–4	20+
Links	No	Yes
Countries collaboration	No	Yes
Co-citation map	Yes	No
Density map	No	Yes
Approaches occurrence	No	Yes
Tools	No	Yes
Branches	No	Yes

[a]A minimum number of occurrences of a keyword

8 Conclusion

This paper aims to review the structure of research, the international collaboration, the trend of AI in agriculture sector as well as the development of framework on the applications of this technology. The current study provides insights on the main applications, techniques, tools, and challenges of AI in agriculture through this framework. It shows an increasing trend in productivity on AIA. The year 2013 was the starting point of an exponential evolution of the number of publications. Fu, Z. is the top author concerning the number of indexed publications followed by Ampatzidis. China Agricultural University, Chinese Academy of Sciences, and the University of Florida are the most influential affiliations. China, the United States, and India are the top three most productive countries on this topic. Research on AIA is turning to agricultural robots, Internet of Things (IoT), big data, deep learning, and internet, etc.

Appendices

Appendix 1 Occurrence of keywords on AI in agriculture field using 2143 documents from 1984 to 2020 and VOSviewer tool

Themes	Key term (occurrence, links)
Artificial Intelligence	Artificial Intelligence (1615 + 25 + 30 + 28, 12,231 + 150 + 178 + 211)
Methods, technique, approaches, and disciplines	Optimization (80, 801), Models & Modeling (64, 774), Economics (53, 581), Climate Models (52, 588), Regression Analysis (51, 564), Fuzzy Logic (53, 470), Feature extraction (48, 434), Computer Simulation (45, 468), Mean square error (39, 456), Surveys (37, 283), Diagnoisis (37, 232), Fuzzy inference (34, 376), Risk assessment (34, 355), Numerical Model (33, 462), Ecology (33,374), Population Statistics (32, 249), Simulation (29, 442), Fuzzy systems (28, 318), Spectroscopy (27, 253), Meteorology (26, 252), Ontology (27, 176), Semantics (26, 202), Uncertainty Analysis (24, 251), Convolution (24, 196), Engineering education (24, 199), Design (22, 150), Performance assessment (21, 229), Nearest neighbor search (21, 220), Fuzzy Mathematics (20, 276), and Detection method (20, 196).
Machine and machine Learning	Learning systems (303, 3003), Machine learning (258, 2357), Deep learning (132, 1019), Support Vector Machines (44 + 77, 484 + 831), Agriculture machinery (118, 1234), (Machine learning techniques (42, 432), Machine learning methods (35, 377), Machinery (33, 295), Machine learning models (21, 242), Supervised learning (23, 236), and Machine Learning Approaches (20, 224).
Algorithms	Algorithm (70 + 69, 838 + 602), Learning algorithms (125, 1286), and Genetic Algorithms (47 + 28, 415 + 291).
Sensors	Remote sensing (178, 1755), Wireless sensor networks (90, 711), Pattern Recognition (47, 342), Sensors (40, 316), Sensor Nodes (36, 307), Infrared Devices (24, 239), Sensitivity Analysis (24, 224), and Sensor Networks (23, 217).
Robots	Agricultural robots (247, 1792), Robotics (57, 350), Unmanned Aerial Vehicles (Uav) (44, 384), Intelligent Robots (29, 176), and Robots (23, 143).
	Data mining (95, 757), Big Data (85, 629), Data Handling (53, 462), Administrative Data Processing (33, 406), Data Acquisition (36, 342), Data analytics (31, 239), Data Set (22, 284), and Data processing (21, 201).
Images	Image processing (104, 839), Image Segmentation (50, 413), Satellite imagery (37, 398), Image classification (34, 342), Image Analysis (33, 312), and Image enhancement (23, 197).
Information	GIS (56 + 81, 672 + 855), Information management (113, 1040), Classification of information (89, 850), Information systems (60, 544), Management Information Systems (35, 428), Information technology (31, 208), Information Services (20, 191), and Global Positioning System (20, 182).

(continued)

Appendix 1 (continued)

Themes	Key term (occurrence, links)
Networks	Neural network (155 + 21, 1393 + 168), Artificial Neural Network (64 + 23, 643 + 180), Convolutional Neural Network (39 + 33, 291 + 268), Deep Neural Networks (30, 284), and Network Architecture (25, 256).
Computer and informatics	Computer vision (68, 533), Automation (74, 526), Antennas (51, 393), Digital storage (40, 394), Clood Computing (34, 246), Soft computing (28, 246), Software (26, 328), Trees (Mathematics) (20, 190), Technology (23, 166), Real time monitoring (21, 162), Supply chains (22, 156), and Computer software (20, 162).
Internet	Internet of things (IoT) 201 + 68 + 39 + 56, 1507 + 591 + 298 + 435), Internet (24, 256), Web services (25, 232), Websites (21, 210).
Systems	Classification (65, 631), Expert Systems (51, 357), Knowledge Based Systems (48, 411), Intelegent System (42, 288), Complex networks (28, 303), Embedded Systems (25, 193), and Classification Accuracy (23, 227).
Environment	Sustainable Development (97, 1006), Monitoring (44, 365), Environmental Impact (43, 562), Mapping (41, 431), Planning (39, 469), Environmental management (38, 443), Environmental Monitoring (36, 453), Sustanability (35, 417), Regional Planning (30, 263), Environmental conditions (30, 258), and Environmental Protection (21, 295).
Water resources and management	Water management (112, 1415), Water supply (76, 1006), Water resources, (72, 844), Water quality (62, 741), Water Conservation (54, 678), Groundwater (51, 676), Watersheds (45, 598), Rivers (33, 462), Water Resource (30, 457), Groundwater Resources (31, 452), Water pollution (31, 368), Aquifers (24, 364), and Reservoirs (water) (20, 262).
Soils	Soils (91, 994), Soil moisture (78, 827), Soil surveys (30, 349), Soil Conservation (21, 280).
Climate and climate change	Climate change (108, 1121), Rain (41, 443), Drought (34, 450), Greenhouses (32, 235), Evapotranspiration (27, 335), and Runoff (20, 281).
Economy	Economic and Social Effects (30, 366), Costs (42, 367), Cost-Effectiveness (33, 336), Commerce (32, 263), Profitability (27, 296), Energy utilization (26, 204), Efficiency (22, 206), and Energy Efficiency (22, 173).
Decision-making	Decision support system (or tools) (72 + 625 + 241 + 82 + 23 + 71, 769 + 5746 + 2622 + 844 + 250 + 752), Decision-Making (323, 3139), Decision trees (101, 1144), Decision Theory (90, 1013), and Decision-making process (24, 251).

(continued)

Appendix 1 (continued)

Themes	Key term (occurrence, links)
Agriculture production and systems	Agriculture (1074, 8500), Crops (342, 3361), Precision agriculture (238, 1980), Irrigation (148, 1695, Smart Agricultures (38 + 89, 327 + 306), Cultivation (130, 1337), Agricultural productions (83, 697), Irrigation system (29 + 29, 396 + 307), Animals (59, 436), Food Supply (58, 586), PLANTS (Botany) (57, 558), Fertilizers (53, 596), Productivity (53, 487), Crop Production (50, 655), Crop Yield (49, 609), Fruits (49, 355), Maize (20 + 27, 280 + 377), Agriculture products (44, 352), Agricultural Management (37, 422), Sustainable Agriculture (34, 345), Smart Farming (34, 253), Farms (33, 384), Precision Farming (33, 253), Nutrients (30, 335), Weed Control (32, 309), Seed (32, 271), Pesticides (30, 242), Nitrogen (28, 325), Plant disease (27, 232),Agricultural industries (26, 197), Agricultural technology (26, 298), Food security (24, 267), Agricultural system (24, 223), Agricultural development (23, 199), Agriculture Production (22, 306), Agricultural fields (21, 182), Agricultural sector (20, 169), and Alternative agriculture (21, 261).
Land use	Land use (80, 974), Forestry (70, 710), Agricultural Land (45, 622), Ecosystems (40, 453), Vegetation (38, 394), Random Forests (31, 410), Landforms (27, 292), Random Forest (26, 342), and Rural areas (23, 205)
Others	Scheduling (29, 328), Procedures (20, 258), Human (30, 315), Stakeholder (24, 324).

Appendix 2 Number of documents, citations, and total link strength of the most influential countries

Country	Documents	Citations	Total link strength
United states	281	3294	137
China	343	1735	95
India	310	1942	63
United Kingdom	66	1131	59
Spain	99	1309	55
Australia	81	1284	51
Germany	69	973	46
Italy	77	1394	45
Iran	59	761	40
Canada	53	620	35
Japan	54	293	34
Netherlands	25	986	27
Malaysia	45	481	24
Saudi Arabia	20	167	23
Brasil	67	562	22
Egypt	29	169	22
France	53	610	21
Greece	54	882	16
Pakistan	27	172	14
Taiwan	31	207	12
Mexico	21	157	11
Colombia	23	52	10
Ireland	26	258	10
Portugal	36	274	10
Russian Federation	43	212	5
Turkey	26	217	5
Indonesia	31	141	3
Philippines	23	46	1

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Enhancing Diversified Farming Systems by Combining ICT-Based Data Collection and Behavioral Incentives: Potentials for South African Agroforestry

Robyn Blake-Rath, Anne Christin Dyck, Gerrit Schumann, and Nils Wenninghoff

Abstract Our world is presently facing major crises in regard to climate, biodiversity, and food security, particularly affecting developing countries, such as South Africa. These can only be encountered by rethinking the way land is managed and used. Diversified farming systems, such as agroforestry, have the ability to generate synergies, contributing to mitigating all three of these crises. In spite of the manifold opportunities provided through agroforestry practices, the adoption and implementation still face several challenges. Regardless of existing approaches, a complete internalization of present externalities together with all-encompassing indicators, measuring ecosystem benefits is currently non-existent, prioritizing the need to develop these in further research. Therefore, immediately feasible and cost-effective behavior incentives are identified, showing the ability to visualize and promote the benefits resulting from these multifunctional, integrated agricultural practices. Enhanced technical possibilities in unarmed aerial vehicles and image sensor technology, as well as advancements in automatic data processing offer increasingly cost-effective ICT solutions measuring the required, communicable data. The identified approaches can help to address key South African agroforestry strategies, regarding policy, knowledge development and adaptation, by

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demonstrating and sharing ascertained benefit awareness, strengthening knowledge development in agroforestry together with creating awareness and disseminating information across all stakeholder groups.

Keywords Agroforestry · Diversified farming systems · Data processing · Behavioral incentives · Nudging · Ecosystem service indicators

1 Introduction

Our world is currently facing three major crises: climate change, biodiversity loss, and the food security crises (WBGU, 2020). The climate-protection goals of the Paris Agreement will most probably not be achieved if decarbonization and the use of land are not changed immediately (IPCC, 2019). Additionally, a human-induced mass extinction can be observed worldwide, reducing the capacity of ecosystems to contribute to climate and food security regulation (IPBES, 2019). Furthermore, the global food system leads to negative environmental externalities threatening our life-supporting systems and simultaneously the system is unable to ensure food security for all (Willett et al., 2019). Current agricultural systems, such as industrialized agriculture, are mostly characterized as monofunctional and production orientated, resulting in negative effects on all three crises (WBGU, 2020). Approximately 23% of the anthropogenic greenhouse gas emissions originate from the global food system, mainly due to deforestation, land use changes from pastures to arable land, fertilizers as well as methane from ruminants, and wet rice cultivation (IPCC, 2019). Land use changes, together with the excessive usage of pesticides destroy habitats as well as endanger biodiversity and are therefore considered as the main drivers of biodiversity loss (IPBES, 2019). Moreover, industrialized agriculture is highly dependent on mineral fertilizers, contaminating soils and water bodies, leading to land degradation (Mateo-Sagasta et al., 2018) as well as dangerous resistances due to a high usage of antibiotics in livestock farming (Cassini et al., 2019).

Therefore, a transformation from monofunctional, production-oriented systems toward multifunctional, ecologically intensive and resilient systems is needed, incorporating the people involved and focusing on agro-ecological practices and the provision of ecosystem services (WBGU, 2020). This transformation should be based on an overall innovative and integrated way of managing land, as a limited resource, utilizing the advantages of the possible multiple benefits that can contribute to mitigating all three crises (WBGU, 2020). In regard to agriculture, multifunctional and diversified farming systems, such as agroforestry, internalize negative externalities and have the potential to meet the requirements of counteracting the negative effects resulting from current agricultural practices (WBGU, 2020). Diversified farming systems as well as landscapes aim at maintaining ecosystem services at multiple scales (spatial and temporal) by intentionally including the biodiversity dimension (Kremen et al., 2012). Agroforestry combines trees with crops and/or livestock on the same plot, leading to synergies regarding climate, biodiversity, and food security (FAO, 2015a, 2019). They are considered as resilient systems (Gnonlonfoun et al., 2019) and can achieve high productivity through the means of intensive support and utilization of ecosystem services (WBGU, 2020). In spite of these benefits, diversified farming systems, such as agroforestry, face several barriers, discouraging farmers to implement agroforestry systems or inhibiting the implementation of related practices (FAO, 2013, 2015b; Ruppert et al., 2020). Eastern and Southern Africa face, in addition to a mosaic of diverse ecosystems, multiple supplementary challenges, including an increasing population, high food and nutritional insecurity, poverty, deforestation as well as water scarcity. Furthermore, a low agricultural productivity, unsustainable wood fuel systems, worsened by disasters and pandemics, have been ascertained (ICRAF, 2021). The provided synergies of agroforestry systems, together with the existing challenges, have been recognized by the South African government (DAFF, 2017). Thereby it is a fundamental challenge to establish appropriate indicators that are not solely output but also impact and result orientated (WBGU, 2020). Thus, all-encompassing indicators, measuring ecosystem benefits and a complete integration of nature's value into the markets by their plain economic value, are currently non-existent (WBGU, 2020). In this context, we assume that the establishment of such comprehensive indicators is a long-term and inertial task. For this reason, we focused on assessing possible alternatives that are more agile and, above all, feasible in the short term. Following this focus, the concrete aim of this article is to (1) investigate the benefits and challenges of agroforestry systems, (2) discuss immediately possible interventions in line with the South African Agroforestry Strategy Framework, contributing to the promotion of diversified farming systems in general and (3) exploring possible ICT solutions for improving the measurement and collection of data opportunities for capturing possible synergies, arising from diversified farming systems.

At first, the benefits and challenges of diversified farming systems are described, focusing on the example of agroforestry. Additionally, the current situation of South African agroforestry, together with the associated strategies addressing the existing challenges is introduced (Sect. 3). In Sect. 4, the power of using behavioral interventions, in particular nudging, in promoting the connected benefits in terms of sharing knowledge and creating awareness for diversified farming systems, is discussed. Technical approaches from the fields of data science, data processing, camera technologies, and unarmed aerial vehicles (UVA) that can be used to collect and communicate the information needed for immediate nudging approaches, as well as long-term measurement of ecosystem services are presented in the fifth chapter. The concluding section (Sect. 6) summarizes the key findings and in addition provides a supplementary outlook, as well as further research opportunities.

2 Illustrating Benefits and Challenges of Agroforestry as a Role Model for Diversified Farming Systems

Agriculture, being the basis of food security, has shaped many parts of our world. Problems arise from non-sustainable land use practices, such as the industrialized agriculture or subsistence farming, both degrading soils and threatening climate change mitigation as well as biodiversity conservation (WBGU, 2020; IPBES, 2019; IPCC, 2019; Willett et al., 2019). One important component in achieving a transformation away from these unsustainable and monofunctional practices toward an integrated way of managing land and combating the crises, is diversified farming systems, such as agro-photovoltaic, aquaponic, climate smart agriculture, climate-sensitive organic farming, paludiculture, permaculture, precision farming, and agroforestry. These represent ecologically intensive, multifunctional, and resilient systems, focusing on agro-ecological practices and the provision of ecosystem services, leading to an improved and sustainable utilization of the limited resource "land" (WBGU, 2020; Kremen et al., 2012). Furthermore, diversified farming systems can be seen as social-ecological systems as they combine traditional and contemporary knowledge with cultures, practices as well as existing governance structures (Kremen et al., 2012).

In agroforestry systems trees are managed together with crops (agrisilvicultural systems; alley cropping or home gardens), livestock (silvopastoral systems), or both (agrosilvopastoral systems) in agricultural settings (FAO, 2015a, 2019) and have the ability to enhance ecological benefits as well as reduce negative externalities (Rosa-Schleich et al., 2019).

They include both traditional and modern land use systems, diversifying and sustaining production based on dynamic, multifunctional, and ecologically founded management systems, in order to increase sustainability benefits in all three sustainability pillars for land users at all scales (FAO, 2019), on the farm as well as on the landscape spectrum (WBGU, 2020). These benefits will be presented, together with the possible shortcomings as well as implementation challenges in the following sections.

2.1 Benefits of Agroforestry Systems for Sustainability

The integration of trees in existing agricultural systems leads to multiple synergies between the different aspects of the agroforestry system and additional benefits for the farmers and society as a whole (Fig. 1; WBGU, 2020). These synergies are increasingly being recognized in scientific research, investigating the advantages of agroforestry systems (FAO, 2015b).

Integrated trees provide shade for both livestock and wildlife, a habitat for beneficial animals, such as insects and birds and can therefore reduce the need for pesticides. Furthermore, trees can recycle nutrients, reduce fertilizer demands, and

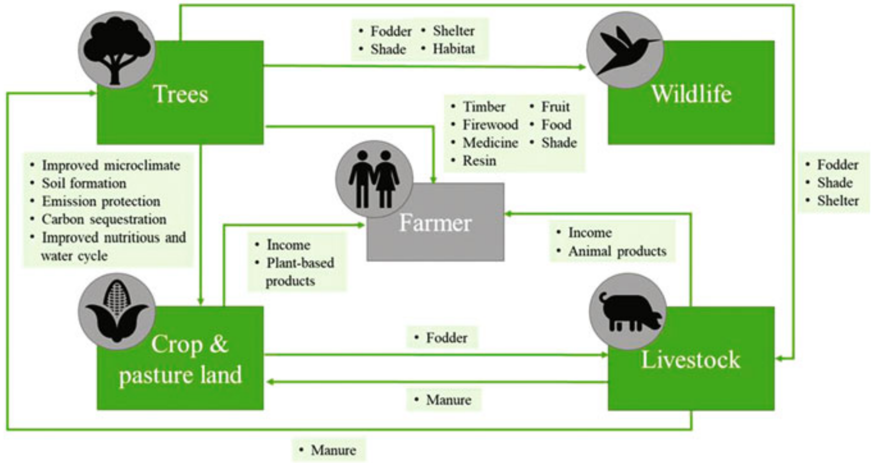

Fig. 1 Synergies within agroforestry systems (following WBGU, 2020)

increase the water holding capacity of the soil (Wangpakapattanawong et al., 2017). In addition to this, a substantial humus enrichment (+18%) was found within the tree rows of agroforestry systems (Seitz et al., 2017). Moreover, trees increase the regulation function, such as storing carbon dioxide, controlling erosion and the microclimate in general, functioning as windbreakers, increasing biodiversity on local as well as on regional level (Lichtenberg et al. 2017), connecting plant and wildlife habitats as well as controlling pests. Additionally, the soil is enhanced through nitrogen fixation, an improved water and nutrition cycle and fertilization (Wangpakapattanawong et al., 2017). Livestock can further provide valuable nutrients for the trees and crops through their manure (Castro, 2009).

Apart from these environmental benefits, not only crops and livestock provide products and income for the farmers involved, but also the integrated trees lead to economic advantages. In South Africa, the integration of Pigeonpea and Maize led, for example, not only to a higher land equivalent ratio, but also provided grain as well as firewood (Musokwa et al., 2018). Products such as fruits, firewood, timber, and resin offer an additional long-term income. Moreover, they can contribute to risk diversification (Nahm & Morhart, 2017) and preserve the added values of the area (Langenberg & Theuvsen, 2018). Furthermore, there are additional cultural benefits resulting from integrated trees. They enhance ecological tourism, add to the beauty of the scenery, supply shade for people and can fulfill religious roles (Wangpakapattanawong et al., 2017). These synergies lead to ensuring food diversity and seasonal nutrition security, diversified rural income, increased resilience in regard to climatic change induced fluctuations (Gnonlonfoun et al., 2019) and assist in protecting and sustaining agricultural productivity capacity as well as perpetuating social and cultural values and regional knowledge (FAO, 2013). In Sub-Saharan Africa, 1106 observations from 126 studies showed that agroforestry practices nearly doubled crop yield production, improved soil erosion control by nine times, enhanced soil fertility by 20%, and led to an improved tree infiltration of water (ICRAF, 2020). In Sub-Saharan African countries, the sustainable integration of legumes can also lead to higher food production rates without the need for more land (Vidigal et al., 2019).

Overall, the introduced benefits demonstrate the possible synergies that can be generated for mitigating climate change, biodiversity loss and contributing to food security within the same ground area. Due to its multifunctional properties, agroforestry is therefore part of the solution in addressing these issues, whether they are environmental, economic, or social (FAO, 2019). By generating an understanding of the relationship and parallels between agro-ecological and agro-economic performance, action recommendations can be made in terms of crop stand, income generation, food production as well as both input and labor requirements. Thus, agroforestry systems can be evaluated in regard to their effectiveness and sustainability (Rodrigues et al., 2009).

2.2 Application and Implementation Challenges of Agroforestry Systems

Besides the manifold benefits and the traditional background of agroforestry systems, there are also shortcomings, barriers, and challenges regarding the application, promotion, and implementation of agroforestry systems. Possible application challenges within agroforestry systems will be presented first followed by a discussion of existing barriers of agroforestry systems in general.

Additional trees compete with the planted crops in regard to space, light, nutrients, and water (Wangpakapattanawong et al., 2017). In order to reduce negative side effects, the systems have to be planned very carefully taking into account the respective local conditions (WBGU, 2020). For this purpose, know-how is needed, as the trees need years to grow and a suboptimal decision will counteract achieving the multiple synergies and can lead to disadvantages. Additionally, it remains unclear how these complex systems will respond to climate change impacts. For these reasons robust projections are needed (Luedeling et al., 2014). Another shortcoming is that the trees not only provide a habitat for beneficial animals but also for pests (Wangpakapattanawong et al., 2017; Nahm & Morhart, 2017). If there is a combination with livestock, it can damage the trees through bite damages and compact the soil via trampling (Spiecker et al., 2009). The diversification of the plot due to tree integration can, additionally, restrain the usage of agricultural machinery and techniques (Wangpakapattanawong et al., 2017), stressing the need for effective foresight system planning, as well as making the usage of remote and small-scale technologies attractive (WBGU, 2020). For the farmer the diversification can therefore be linked to economic costs. These trade-offs between ecological and economic dimensions have to be considered and researched conjointly. In comparison with non-diversified farming practices it can be, on the one hand, found that diversification provides greater biodiversity as well as ecosystem service (e.g., pest and weed control, soil health, carbon sequestration). Nevertheless, these benefits cannot currently outweigh short-term economic costs. In the long-term diversification can, on the other hand, lead to higher and stabilized yields, risk reduction, and an increased profitability. As a result, combined diversified farming practices can provide both higher ecological and economic benefits (Rosa-Schleich et al., 2019).

In addition, challenges and barriers exist concerning the promotion and implementation of agroforestry systems. A barrier for adapting these practices is the delayed return on investment connected to the growth rate of trees in comparison to most crops. The profit made from the integrated trees by producing positive net values over time and the resulting break-even point occurs after years for some systems (FAO, 2013, 2015b). As a result, farmers may have to invest years before the returns begin reimbursement. A further major challenge regarding the promotion and implementation of agroforestry systems lies in the often-unclear status of land and tree resources. Land delineation confusion and unclear rights, resulting from both unsecured and/or ambiguous land tenure, are common in developing countries and can lead to people being discouraged. This prevents them from implementing or continuing agroforestry practices. With perennial land rights being unclear the needed long-term investments in agroforestry are inhibited. Additionally, there can be forest regulations, restricting harvesting, cutting, or selling tree products from on-farm trees (FAO, 2013, 2015b). Furthermore, tree product markets are identified to be less efficient as well as less developed than markets for crops and livestock commodities. Also, value chains related to agroforestry systems receive little support. Based on this, tree product markets can be considered as underdeveloped, making agroforestry practices unattractive (FAO, 2013, 2015b).

Furthermore, agriculture policies often solely offer incentives for certain "commercial" agricultural models, such as monocultural systems and industrial agricultural production (IPBES, 2019; FAO, 2015b). Price supports or favorable credit terms also mainly grant these systems. These, however, hardly ever consider trees, resulting in an additional aspect discouraging the adoption of agroforestry practices (FAO, 2013, 2015b). Besides legislation supporting industrial agricultural systems, existing regulations often penalize practices needed to implement agroforestry systems. This also applies to tax regimes, as they mainly favor agricultural land compared to forests (FAO, 2013, 2015b). Furthermore, both externalities resulting from industrial agriculture and non-economic benefits from ecosystem services not being currently internalized and represented in the prices, lead to misdirected incentives and prohibit the implementation of multifunctional and diversified farming systems (WBGU, 2020). The multifunctionality of agroforestry systems along with the resulting cross-sectional attributes leads to a further challenge, as a lack of coordination between these sectors is still present. Existing gaps and adverse incentives that are working against the development of agroforestry systems result from policy conflicts, omissions, differing organizational cultures and objectives between the multiple sectors (FAO, 2013, 2015b). Moreover, most parties are not aware of its humanitarian value, since they are inappropriately and in-transparently communicated (Leopoldina, 2020).

The mentioned challenges together with a continuously predominant focus on conventional agricultural methods and the lack of knowledge regarding sustainable diversified farming approaches and alternatives, restrict the interest of policy-makers in agroforestry development. As a result, the resources available for research, dissemination, market information and therefore the bases for addressing the existing challenges and widely spreading agroforestry practices, are negatively influenced (FAO, 2013, 2015b). This limited awareness of the advantages of agroforestry can lead to a widespread scepsis among farmers. Small agricultural plots, a lack of information as well as missing public support increase this notion in particular. In Kyrgyzstan, for example, farmers feared a decrease in yields due to the shade incurred by implementing trees in the form of windbreaks. They were not aware of the beneficial side effects such as timber provision, higher yields, and reduced soil and wind erosion (Ruppert et al., 2020). Therefore, active support through the local government and cooperative models should be pursued (Ruppert et al., 2020).

The establishment of appropriate indicators that are not solely output but also impact and result orientated depicts a further challenge (WBGU, 2020). Measurable indicators, assessing agronomic and economic services, productivity as well as crop sustainability are paramount to improving the management of agroforestry systems. Ecological indicators, for example, are communicable, facilitating a simplification of the highly complex human–environmental systems (Müller & Burkhard, 2012; Van Reeth, 2013) so that they no longer remain gratuitous (Leopoldina, 2020). Ecosystem services are generally defined as goods and services provided by ecosystems that are beneficial for humanity (MEA, 2005). The cost of destruction appears usually in the far future and the benefits remain underestimated. This lack of appreciation is one of the main drivers of the current biodiversity crisis and the related effects on the climate and food crises (Leopoldina, 2020). The need for integrated indicators reflecting these benefits is increasingly claimed by governments, nongovernmental organizations (NGOs) as well as the private sector, in order to include them into decision-making processes and public communication (Olander et al., 2018; National Research Council, 2005; PCAST, 2011). Currently, biophysical proxies, such as forest cover, are often implemented, services that appear difficult to measure are disregarded or they are not evaluated, due to a mistrust of valuation methods for non-market services (Olander et al., 2018; WGBU, 2020).

There are existing approaches providing or improving indicators measuring ecological or social impacts, such as the identified selection of possible indicators for each of the 18 ecosystem services (IPBES, 2019) or the development of new types of indicators reflecting the ecosystem's capacity to provide benefits to society, such as the benefit-relevant indicators (Olander et al., 2018). Other approaches, such as Payments for Ecosystem Services (PES), aim at ensuring a sustainable ecosystem management also highly depend on adequate measures and indicators (WBGU, 2020), as these support positive environmental externalities through the transfer of financial resources from beneficiaries of certain environmental services to the providers of these environmental resources (Wunder et al., 2020; Wunder, 2015). However, research on integrated, context-oriented indicator development for performance assessment stays underrepresented (e.g., Rodrigues et al., 2009) and an overall need for further research remains of fundamental priority (WBGU, 2020).

Furthermore, case-specific indicator aggregation levels have to be considered due to the science-policy dilemma. On the one hand, science prefers to increase the indicator amount, improving security and accuracy, while, on the other hand, politics are content with fewer indicators. Therefore, the selection and development of indicators need to remain understandable and applicable for decision-makers (Van Reeth, 2013), as well as accurate for scientific purposes. A possible satisfying aggregation level could be, for example, the request for combining all ecosystem services of a specific area within a single value (e.g., monetary), resulting in losing certain specialties or risks (Müller & Burkhard, 2012). An important long-term goal should therefore be both the development and improvement of scientific indicators that are orientated at the Sustainable Development Goals (SDGs), Convention on Biological Diversity (CBD) as well as the Paris Agreement (WBGU, 2020).

3 South Africa's Vision and Strategy for Agroforestry Development

The multiple social, economic, and ecological benefits, as well as the identified challenges faced by agroforestry, have also been recognized by the South African government. The Department of Agriculture, Forestry and Fisheries (DAFF) therefore published the "Agroforestry Strategy Framework for South Africa" in 2017. This framework includes relevant literature, the key challenges for the development of agroforestry, a vision for the development of agroforestry in South Africa and all related key principles, together with the actual implementation strategy. The following section provides a brief overview of the key content of this strategy framework.

> To achieve the integration and mainstreaming of agroforestry as an accepted land use that contributes to food security, improved livelihoods and income generation while building resilient, climate smart systems that sustain our natural resources
>
> —South Africa's Vision on Agroforestry (DAFF, 2017)

To achieve the vision, the framework presents three key strategic themes as the basis for agroforestry development. These include "creating the enabling environment for agroforestry (*Policy*)," "developing the science of agroforestry and demonstrating the benefits and developing the skills of agroforestry (*Knowledge Development*)," as well as "adopting and integrating agroforestry into the landscape for social and economic benefit (*Implementation*)." Each of these key themes is in turn characterized by individual goals and actions:

Policy: This key theme is characterized by two major objectives: "support leadership and institution," together with "unlock resources to support agroforestry research and implementation." The first objective involves, developing a common understanding of agroforestry in South Africa, supporting the inclusion of agroforestry in the implementation of current policy, specifying agroforestry as a sustainable practice in the development of future policy, establishing institutional structures and systems to support the strategy, as well as promoting agroforestry systems that are appropriate for the various land tenure systems in South Africa. To achieve the unlocking of the required resources, it is planned to provide government funding to support agroforestry, to release additional resources, as well as to provide incentives for the adoption of agroforestry (DAFF, 2017).

Knowledge Development: The key theme "*Knowledge Development*" is divided into the "strengthening of knowledge development in agroforestry" and the actual "implementation of agroforestry research." To achieve the strengthening of knowledge development, it is planned to conduct knowledge audits and establish centers of excellence together with an agroforestry information system for South Africa. For the concrete implementation of agroforestry research, the goal is to develop a research agenda for agroforestry, document relevant agroforestry initiatives, and identify and test agroforestry systems that fit the climatic, environmental, and socioeconomic conditions of the country. In addition, further research will be conducted to optimize positive and minimize negative interactions among agroforestry system components, as well as generate the argument for the advantages of agroforestry practices. Another goal is to conduct plant breeding research to improve germplasm (DAFF, 2017).

Implementation: In order to carry out the actual adoption and integration of agroforestry into the landscape, the vision strategy envisages four main objectives: "sharing knowledge and information about agroforestry," "developing skills in agroforestry," "enabling the adoption of agroforestry," as well as "providing general support." To achieve the sharing of knowledge and relevant information on agroforestry, the strategy envisions the creation of general awareness, the dissemination of information across all stakeholder groups, and the linkage of natural resource management extension services and professionals with researchers. Skills development in agroforestry is supposed to be achieved through training curricula in schools, colleges, and universities, advanced training of consulting personnel, and training of farmers and practitioners. For the actual implementation of agroforestry, the plan is to organize and mobilize farmers for agroforestry, to provide seeds and seedlings, to develop markets for agroforestry products, and to offer targeted and long-term advice. The "Support" envisions integrating agroforestry into existing programs in order to assist farmers in implementing agroforestry practices, identifying existing successful agroforestry initiatives as well as supporting and replicating these approaches (DAFF, 2017).

4 Behavioral Incentive Opportunities Creating Awareness and Promoting Synergies

As previously discussed, all-encompassing ecosystem indicators reflecting also the social and environmental synergies resulting from diversified farming systems, such as agroforestry, are currently non-existent (Sect. 2.2; WBGU, 2020). These, however, build the bases for internalizing externalities, providing a foundation for developing appropriate incentive-based regulation and policy instruments (e.g., subsidies), certification processes as well as both information-based political and consumer decision-making, raising awareness of their consumption consequences (WBGU, 2020). The priority therefore lies on developing, all-encompassing, communicable ecosystem service indicators for diversified farming systems, such as agroforestry, in order to counteract the existing barriers. Simultaneously, some challenges addressed by the Agroforestry Strategy Framework for South Africa, may be already approachable even considering the lack of measurable and appropriate indicators. When the implementation of heavy-handed interventions is difficult, softer behavioral interventions may offer a powerful alternative (Madrian, 2014). This may be especially applicable regarding the identified key strategy section "*Knowledge Development*" of the DAFF (2017). The World Bank Group (2015) published the "World Development Report" in 2015, focusing on these aspects and opportunities.

In the following section, we will address different possibilities from the field of behavioral interventions such as measures related to nudging. In this context, it should be noted that we are aware of the quite critical debate regarding this topic. However, whether nudging impairs personal autonomy (e.g., freedom of choice, autonomy of will, rational action, and freedom as non-determination) or is manipulative (Schmidt & Engelen, 2020) will not be part of our study. Instead, our goal is to identify opportunities from the field of behavioral interventions that could have the ability to demonstrate the benefits and develop the skills of agroforestry, strengthen agroforestry development knowledge, share know-how and information on agroforestry practices, and create awareness by complementing existing incentives.

Most people make decisions based on automatic as well as socially thinking founded on mental models. While thinking automatically, a simple "nudge" could change their behavior without changing the set of choices. Nudges do not forbid, reward, or penalize particular choices and as an alternative, change the default option (description, anchor or reference point) and as a result, point individuals toward a particular choice (World Bank Group, 2015). An important aspect of the associated choice architecture is simplicity and a context-orientation (Madrian, 2014). Manifold or complex options could lead to people avoiding thinking through a decision, postponing active decision-making, or choosing error-ridden options (World Bank Group, 2015).

Regarding the production of collective goods, different actions can be encouraging. One cost-efficient possibility is to award peer esteem for certain levels of achievement (World Bank Group, 2015). This can be illustrated by a study investigating contributions of Wikipedia, an online encyclopedia, based on voluntary efforts. Peer esteem in the form of a "Barnstar" (publicly visible editing award) was randomly awarded. The result was that on average 60% of the awardees were more productive over the course of the 90 days after receiving the award than members of a control group (Restivo & van de Rijt, 2012). Even though the recipients did not receive immediate material benefit from the inexpensive reward, a substantial effect on productivity was observed. This could additionally lead to sustaining future volunteer effort (World Bank Group, 2015).

Conditional cooperation could, in addition, help to manage common goods (World Bank Group, 2015). A study from Rustagi et al. (2010) focusing on forest user groups in Ethiopia, revealed a variation of conditional cooperators within the observed groups. As a result, the study emphasizes the fact that people do not always act selfishly regarding common good management. Groups, who proved to be more successful in managing forest commons, had a higher share of conditional cooperators. In this setup these groups spent on average 1.5 times more time conducting forest patrols. A key value enforcing cooperation by conditional cooperators is costly behavior monitoring (Rustagi et al., 2010). These findings demonstrate that an important factor of managing common goods is voluntary cooperation. This, however, is fragile, as the expectations about others' cooperation contribute to the individual willingness to cooperate (World Bank Group, 2015). People tend to select institutions with like-minded cooperators, using efficient punishment to sustain cooperation, when given the chance (Gürerk et al., 2006; Fehr & Williams, 2013). Policy-makers should therefore take selfish instincts as well as cooperative instincts into account when examining certain interventions and societal institutions. Investing in opportunities for actors to observe the behavior of others can be advantageous by enhancing the expectations and practice of cooperation. This can be realized, for example, by making people's behavior more public (World Bank Group, 2015), such as revealing engagement in agroforestry activities in the surrounding area, a specific region or country.

While economic incentives are known to influence behavior, less attention has been given to the fact that social incentives can also have powerful effects on behavior. The latter can, for example, in the form of status and recognition, motivate people to engage and can be a substitute for monetary rewards in certain situations (World Bank Group, 2015). These may be particularly remunerative when the quality of the individual performance is difficult to measure precisely (Besley & Ghatak, 2008) or there is a lack of financial resources (World Bank Group, 2015). This depicts a particularly interesting possibility, in addressing the challenges in the current agroforestry situation, as both aspects are present. A cost-effective approach is ranking schemes. Actions can be shifted by rewarding certain performances, on the one hand, and shaming underperforming outputs on the other. As a result, it can be deduced that indicators therefore do not only provide information on the performance. They serve as additional generalized psychological rules (Sinclair, 2005) that break down and frame provided information according to a certain perception of a "good society" (World Bank Group, 2015). Furthermore, they enable a comparison that can motivate multitude actors. These can range from citizens, NGOs, and elites to governments (Davis et al., 2012).

An example of a social incentive in the form of social comparisons that aims at reducing energy consumption is illustrated by an energy conservation program in the USA. Households were mailed “home energy reports.” These reports contained information on the household’s electricity consumption, comparing it to the amount used by others in the neighborhood within the same time period. This simple incentive led to a 2% reduction in energy consumption. This decrease is equivalent to reductions resulting from short-term increases in energy prices of 11–20% and a long-term increase of 5% (Allcott, 2011; Allcott & Rogers, 2014).

These examples illustrate that aiming at a complete integration of nature’s value into the markets by their plain economic value is not necessarily crucial for demonstrating, sharing, and promoting the benefits resulting from an integrated way to manage land via diversified farming systems, such as agroforestry. For these targets it is of paramount importance to make the systemic contributions of ecosystems visible as all-encompassing, appropriate, and standardized indicators are currently not available and therefore the beneficial synergies and generated ecosystem services are still often excluded from economic decisions (WBGU, 1999, 2020; Helm & Hepburn, 2012). The identified behavioral opportunities also motivate the need for measuring communicable data, representing exemplarily possible synergies and ecosystem services generated by agroforestry systems. For this purpose, the measured data, however, does not have to cover all-encompassing indicators, making it independent from this long-term goal and already presently feasible. Either way, data has to be collected and processed in order to provide communicable information. Technical hard- and software possibilities as well as different options from the field of data science are discussed in the following section.

5 Technical Solutions and Data Processing Possibilities Measuring Agroforestry Data

Technical tools for agroforestry focus mainly on three areas: Data collection, processing, and utilization. A review by Pádua et al. (2017) analyzes different concepts for data collection and processing. Data collection is divided into sensors and sensor platforms. Traditional sensor platforms include satellites or human-crewed aircrafts. Civilian drones are used as a new unmanned alternative. Each platform offers both advantages and disadvantages. Satellites can cover large ground areas and a wide spectrum. The costs, however, are very high and the resolution of images is low. Additionally, coverage can regionally vary. Aircrafts can also cover large areas, offering a higher resolution than satellites. However, this approach is also costly and highly weather dependent. Furthermore, the monitored area must be within the range of an airport. As a modern alternative, unmanned drones can be utilized and can be divided into fixed-wing and multirotor drone categories. The costs for acquisition and operation are lower simultaneously guaranteeing a high resolution. Furthermore, the dependence on the weather is lower, due to the fact that unmanned aerial vehicles (UAV) are not affected by clouds, unlike aircraft and satellites (Pádua et al., 2017).

The described vehicles serve only as a platform for the required sensors, such as the currently mainly used imaging sensors. These in turn can be grouped into active and passive sensors. RGB sensors, like digital single-lens reflex cameras (DSLR), are widely applied, capturing images similar to the human eye. UAV specific as well as consumer hardware can be appropriate for RGB sensors. These cameras mainly offer a new viewing angle, simultaneously capturing images familiar to those of the human eye (Pádua et al., 2017). These sensors can be used, for example, in the field of biomass monitoring (Bendig, 2015). IR cameras collect image material within the infrared light spectrum, not or barely visible for humans. Consumer cameras can be used for near infrared spectrums (NIR), as they often actively filter the infrared spectrum. By changing the filter, this specific spectrum can be measured. Images from NIR cameras can provide additional information on plant growth. An enhanced density of growth results, for example, in an increased infrared light reflection. Far infrared (FIR) cameras can record light of the infrared spectrum, which cannot be seen by the human eye. The resulting images provide information about the temperature of the recorded objects. FIR cameras have a lower resolution and are more expensive than the previously described technologies due to their specialization and complexity (Pádua et al., 2017). Thermal cameras have been implemented, for example, to detect wildlife (Israel, 2012). Multi- and hyperspectral cameras combine different spectra and can record RGB and IR information, for example, simultaneously. However, these cameras are significantly more expensive although offering a much higher resolution than consumer hardware. However, the UAV must be able to transport these cameras, since they are larger and heavier than RGB cameras (Pádua et al., 2017). Multispectral cameras for example can be used to estimate the nitrogen status (Caturegli et al., 2016) while hyperspectral cameras can be implemented to estimate additionally chlorophyll (Bamgbade et al., 2012; Li et al., 2020) or plant diseases (Zhang et al., 2020). Active sensors can also be used in addition to the previous described passive sensors. Examples are light imaging, detection and ranging (LIDAR) sensors, which can create a three-dimensional model using lasers (Pádua et al., 2017). These can be utilized for biomass estimation, for instance (Wang et al., 2016). For various reasons, the raw data must be pre-processed before usage. Poor quality images, caused by turbulence or technical defects can be removed or, if possible, repaired afterwards (Pádua et al., 2017). In many cases, multiple photos are combined to form one large overall image. In this regard, scale-invariant feature transform (SIFT) algorithm can be a possible method (Jia et al., 2015). To extract information from the images, spectral indices are used. These can be burned area measurements or indices for water and snow. Vegetation indices, however, are most commonly used. These calculate the amount of photosynthetic material based on the image information. Besides biomass, other information can be extracted, such as nitrogen content, potential diseases, or assistance in crop management (Pádua et al., 2017). When images are captured by implementing passive

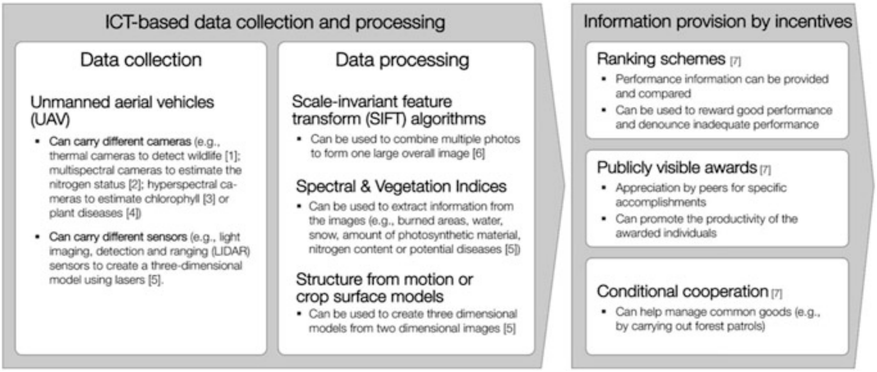

Fig. 2 Conceptual framework and identified potentials (based on: [1] Israel, 2012; [2] Caturegli et al., 2016; [3] Bamgbade et al., 2012, Li et al., 2020; [4] Zhang et al., 2020; [5] Pádua et al., 2017; [6] Jia et al., 2015 & [7] World Bank Group, 2015)

sensors, usually only two dimensions are captured and the third dimension (height) is lost. The height of trees, however, is a relevant information source in agroforestry management. Using methods, such as the structure from motion or crop surface models, three-dimensional models can be created from two-dimensional images. A more accurate result can be obtained by measuring with a LIDAR sensor (Pádua et al., 2017).

By using UAVs in combination with the presented camera possibilities, information of previously unattainable quality, quantity, and dimension can be obtained, providing the foundation through precise information. By doing so, agroforestry practices can be optimized and documented, future required data in regard to establishing indicators as well as illustrative data can be provided, supporting behavioral incentives (Sect. 4), contributing to the knowledge development goals of the South African agroforestry strategy (Sect. 3).

As can be seen in Fig. 2, our approach assumes that the data collection can be achieved using UAVs such as private drones. Since drones can violate privacy, data protection rights, and public peace, an important requirement in this context is compliance with regional regulations. However, in Africa in particular, it is very cumbersome to acquire an appropriate license to operate drones due to either very restrictive or outright lack of regulations (Ayamga et al., 2021). Note, therefore, that our approach assumes a scenario in which the use of a drone faces beneficial regional regulations. Data can then be processed using scale-invariant feature transform (SIFT) algorithms, indices (e.g., spectral and vegetation) as well as models creating three-dimensional visualizations from two-dimensional images. This processed information sets the basis not only for enhancing the cultivation and monitoring of diversified systems (e.g., agroforestry) and not easily accessible areas, but also for behavioral incentives creating awareness and promoting synergies. Ranking schemes, publicly visible awards, and conditional cooperation have been identified as approaches with a high potential in this regard.

6 Summary and Conclusion

As current agricultural systems lead to negative externalities endangering climate change mitigation, biodiversity, and future food security, the need for a transformation from monofunctional, production-orientated systems toward multifunctional, ecologically intensive and resilient systems, focusing on agro-ecological practices and the provision of ecosystem services incorporating the people involved is therefore paramount. The foundation should generally be based on an overall innovative and integrated way of managing land, focusing on multifunctionality and the generation of possible synergies between the three different land use demands. Multifunctional and diversified farming systems, internalizing external effects, have the potential to meet these requirements in agriculture. In order to gain a detailed insight, the connected benefits, together with the existing challenges of agroforestry systems, which combine trees with crops and/or livestock in the same area, have been investigated. Integrated trees provide positive synergies for biodiversity as they benefit wildlife (e.g., shade, habitat, reduced pesticides and fertilizers), climate change (e.g., water retention capacity, humus enrichment, stored carbon dioxide, erosion control), and food security (e.g., fruits, improved agricultural production capacity, seasonal nutrition security, increased resilience) as well as perpetuate local knowledge, together with social and cultural values. Additionally, trees generate cultural benefits (ecological tourism, scenery, religious roles) and their products such as fruits, firewood, timber, and resin offer an additional long-term income, contributing to risk diversification. In spite of these benefits, agroforestry implementation faces several challenges, discouraging farmers to implement agroforestry systems or promoting related practices, such as a delayed return on investment and unsecured land tenure. This can result in farmers not adopting or continuing agroforestry practices. Furthermore, existing regulations and policies mainly support conventional agriculture, leading to disadvantages for agroforestry. Moreover, limited awareness of the advantages leads to both restricted interest of policy-makers in regard to agroforestry development (insufficient resources allocation) and general widespread skepsis among farmers, inhibiting agroforestry promotion, implementation, and propagation. The fundamental challenge is, however, the establishment of appropriate indicators that are not solely output but also impact and result orientated, such as ecological or ecosystem service indicators. This lack of appreciation and underestimation of these services are key drivers of the current biodiversity crisis and the related effects on climate change and the food crises. Improved indicators have the ability to build the foundation for incentive-based policy instruments, certification processes as well as providing both information-based political and consumer decision-making, raising awareness of their consumption consequences. In spite of existing approaches, a complete internalization of existing externalities and all-encompassing indicators, measuring ecosystem benefits are currently non-existent.

Simultaneously to further research in developing and improving scientific indicators (orientated at the SDGs, CBD, and Paris Agreement), actions toward promoting agroforestry practices can be undertaken, visualizing the systemic contributions of ecosystems, as these are often excluded from economic decision-making processes. Immediately feasible solutions could, for example, be found by utilizing behavioral interventions, promoting the benefits of diversified farming systems, and complementing economic incentives. The latter are, on the one hand, already known to influence behavior, although, on the other hand, are dependent on the non-existent indicators. Ranking schemes can be a cost-effective approach, shifting actions, by both rewarding certain performances and shaming underperforming outputs. In this context, indicators not only provide performance information but, furthermore, enable a comparison, motivating multitude actors. A "nudge" may change behavior without prohibiting, rewarding, penalizing, or altering the set of choices and alternatively changes the default option, pointing individuals toward a particular choice. Regarding the production of collective goods, a cost-efficient possibility is to award peer esteem for certain levels of achievement. A substantial effect on productivity was observed, leading to sustaining the future volunteer effort, even though the recipients do not receive immediate material benefit from the cost-effective reward. As a result, voluntary cooperation can be assessed as an important element of common good management. Both selfish and cooperative instincts should therefore be taken into account by policy-makers when examining certain interventions and societal institutions. Investment in actor opportunities, observing the behavior of others, can be useful, by making people's behavior and agroforestry actions more public, enhancing expectations and practice of cooperation as a result.

As all-encompassing, case-specific, and comparable indicators are currently not existent, there is the need to prioritize the development. In this regard, the identified immediately feasible and cost-effective behavior incentives show the ability to demonstrate, share, and promote the benefits resulting from an integrated way to manage land via diversified farming systems such as agroforestry. In order to measure future detailed ecosystem service indicators as well as immediately communicable data for behavioral incentives, technical approaches can be utilized. In this regard, the advancing digitalization offers both hard- and software ICT opportunities in the field of remote sensing, image recognition, and data science. Appropriate technical tools for agroforestry focus mainly on data collection, processing, and utilization. The promotion of agroforestry practices via behavioral approaches can benefit greatly from enhanced UAV and image sensor technology, as well as persistent progress in automatic data processing. These advancements enable large ground area monitoring and previously impossible analyses performance. In addition to these new innovative possibilities, the costs are decreasing, due to the fact that components from the consumer sector can be used in addition to professional hardware. This development is expected to continue in the future.

Behavioral incentives have therefore the ability to enhance diversified farming systems, such as agroforestry, by overcoming existent promotion barriers using advancements in ICT technology, as shown in the illustrated examples. Both the synergies and the existing challenges in the context of agroforestry development have been recognized by the South African government. In order to increase the implementation of these multifunctional systems, behavioral incentives can help to address key South African agroforestry strategies immediately and with regard to the currently available measurement approaches, regarding policy, knowledge development and adaptation, through demonstrating and sharing ascertained benefit awareness, strengthening knowledge development in agroforestry as well as creating awareness and disseminating information across all stakeholder groups.

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Information as a Service Communication Framework for Dairy Farmers

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Abstract South Africa has a market-oriented agricultural economy. New digital innovations and technologies in the agricultural sector are revolutionizing the industry and improving sustainability. Organizations are increasingly providing their customers with different kinds of information as a service. The dairy industry is one of the largest agricultural industries in South Africa, employing more than 40,000 people. Dairy farming is extremely price sensitive and therefore information that can assist in decision-making plays an important role for farmers. The increased use of mobile technologies is changing the way dairy farmers access information. This chapter focuses on the South African dairy farmers' information requirements and customer satisfaction with agricultural organizations' information services. A survey exploring the information requirements of South African dairy farmers and agricultural organizations information services was conducted amongst 96 dairy farmers in South Africa. The farmers' primary use of mobile devices was for business purposes, specifically access to information regarding dairy production and market indicators. Agricultural organizations could benefit from embracing new digital technologies and exploring new ways to provide information as a service to their farmer clientele base. Finally, a proposed Information as a Service communication framework for dairy farmers is provided.

Keywords Mobile technologies · Information as a service (IaaS) · Dairy farmers · Agricultural information

1 Introduction

Agriculture plays an important and critical role in every country's economy and is the main source of national income for most developing countries. Digital transformation in the agricultural sector can provide increased opportunities to address food

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security challenges, sustainability, and job creation (Aguera et al., 2020). In developing countries, such as India, over 70% of the rural households depend on agriculture. Agriculture provides approximately 52% of the total number of jobs available in India and contributes around 18% to the gross domestic product (GDP) (Arjun, 2013). In South Africa, the agriculture sector contributes 4% to the GDP, however agriculture was the only sector that posted a positive growth figure in the last quarter of 2020 (Stats SA, 2020).

Modern agricultural production is not possible without the implementation and use of modern technologies and reliable and up-to-date digital information about farm operations. Farmers increasingly have to rely on digital technologies, such as sensing and monitoring devices, advanced analytics and smart equipment. Agricultural production is rapidly changing toward sustainable smart farming systems, driven by the rapid pace of technology development, including cloud computing, the Internet of Things (IoT), Artificial Intelligence, machine learning, and data-driven applications (Akbar et al., 2020). Information as a Service (IaaS) is an emerging cloud business model in which a company shares or sells relevant information to another company or individuals to perform their business.

The demand for milk is continuously increasing due to the increasing population of the world. Developed countries consume more dairy products compared with developing countries. To meet this increased demand for milk products, better technological techniques for improving milk yield are required. Dairy farmers are increasingly introducing new digital technologies that create greater opportunities for sustainable smart dairy farming. The increased use of digital information can assist dairy farmers to overcome different traditional farming challenges, become smart dairy farms, and increase the milk production in a sustainable manner (Akbar et al., 2020).

Agricultural produce is perishable, seasonal, and generally bulky; therefore, it is important to receive appropriate information at the right time for markets to function effectively. A farmer is always in need of information, whether it is in the starting phase of planning to produce a crop or in the phase where the farmer must market produce. Farmers, in general, have little know-how about market conditions and this is why there is a need for relevant market information in most developing countries (Karim et al., 2020; Svensson & Yangizawa, 2009). A major factor influencing agriculture farmers globally has been access to market information (Barrett & Davidson, 2008), hence it is important to know the reach and influence of market information services to farmers (Sakabira et al., 2012).

Communication with an organization's customers has become one of the most important factors that play a role in doing business. Organizations that supply their customers with correct and different kinds of information build customer loyalty. Dairy farmers are no exception to the rule because of the ongoing planning that dairy farmers need to do on a daily basis in order to remain sustainable. Dairy farming in South Africa is very price sensitive and therefore information that can help in decision-making will play a very important role in making the right decision at the right time.

There are a number of different avenues that farmers can use to find accurate and reliable market information, specifically using digital technologies. However, in some developing countries, it is more difficult to access information because of the lack of infrastructure and connectivity (Thapa et al., 2020; Barrett & Swallow, 2006). The markets need to be equipped with adequate infrastructure facilities so that up-to-date price information can be made available to the farmers who require it. In developing countries, access to the market helps alleviate poverty by commercializing agriculture, which results in a more uniform distribution of income.

Information costs have been drastically reduced by the advent of Information Technology (IT) in agriculture, which made information easily accessible. IT is any device or application that permits the exchange or collection of data through interaction or transmission (Lusch & Vargo, 2014; Tilson et al., 2010). The following costs have been reduced through the use of IT in agricultural marketing, namely, transaction costs, information search costs, travel costs, and a reduction in wastage or spoilage (Lusch & Vargo, 2014). IT applications can assist farmers to make informed decisions, negotiate with the traders, determine which market to sell in, whether to store surplus and to plan for future crops (Mwakaja, 2010; Jairath & Yadav, 2012). IT has emerged as an essential tool in agriculture. This is evident in Kenya, where for example, an app called ICOW was developed and is used to upskill animal farmers in East Africa (https: //icow.co.ke/).

The information requirements of dairy farmers in South Africa are an important topic, as dairy farming is a significant contributor to the National Domestic Product (NDP) and employment creation. The objective of this study was to determine the IaaS required by dairy farmers and their satisfaction with information provision by agricultural organizations. In order to achieve this objective, an IaaS for Dairy Farmers survey was conducted amongst South African dairy farmers. The survey targeted individual dairy farmers involved in, or associated with, dairy farming in South Africa. The chapter is structured as follows: The problem investigated and research objective are presented in Sect. 2. A literature review (Sect. 3) investigates the information requirements of dairy farmers and the technologies available and the research methodology are presented in Sect. 4. The results of the research, including a discussion on the relevance of the findings, are presented in Sect. 5. The proposed IaaS Communication Framework for Dairy Farmers that will provide IaaS to dairy farmers in South Africa, is presented in Sect. 6. Finally, conclusions and recommendations are provided in Sect. 7.

2 Problem Investigated and Research Objective

The dairy industry is changing and farmer's information requirements are reshaping the industry and agriculture organizations need to provide new information services. The dairy industry is experiencing constant changing technological innovations and increased customer expectations. Agricultural organizations need to be aware of farmers' information requirements and their use of technologies for information retrieval (Raza et al., 2020; Thapa et al., 2020).

The main research problem addressed in this chapter is that the information as a service is not being used optimally by agricultural organizations in South Africa, to assist dairy farmers with farm management and decision-making. In South Africa, limited research has been conducted on the information requirements of dairy farmers. The objective of this study is to investigate the importance of information for dairy farmers, agricultural organizations' information provision, and the customer satisfaction with an international agricultural service provider's information provision in South Africa.

3 Literature Review

The agricultural industry has been revolutionized by modern farming technologies and techniques. The new way of thinking and operating for agricultural organizations is through digital transformation that transforms the way the organizations provide information and interact with customers (Aguera et al., 2020). IaaS is an emerging cloud business model in which a company shares or sells relevant information to another company or individuals to perform their business. Farmers are increasingly making use of mobile technologies and applications to retrieve information. Applications (Apps) can be installed onto mobile devices, which provide additional functionality and access to information. Mobile Apps typically provide users with information services, access to market indicators, including dairy farm and herd management (Karim et al., 2020).

3.1 The Dairy Industry in South Africa

The dairy industry in South Africa is one of the largest agricultural industries in the country, employing more than 40,000 people. The demand for milk is continuously growing due to the increasing global population (Akbar et al., 2020). *Milk South Africa* is a governmental institution entrusted to administrate statutory regulations in pursuit of its strategic goals in order to broaden the market for milk and other dairy products and improve the international competitiveness of the dairy industry (MilkSA, 2021).

Since 2015, milk has become a sought after product and experiences substantial price fluctuations (Akbar et al., 2020). The South African dairy industry is one of the most deregulated industries internationally. The industry is not subject to any statutory intervention in the marketing of its products and it is not supported by government subsidies. A totally free and competitive dairy market prevails in South Africa (MilkSA, 2021). A total of 3.16 billion liters of milk were produced by dairy farmers in South Africa in 2016. The national herd is estimated at 1.3

million dairy cows of which approximately 50% are cows in production (MilkSA, 2021). The coastal provinces in South Africa supply the majority of milk in South Africa. Unprocessed milk production for April 2020 was 241 million liters, 2.83% less than in April 2019.

3.2 Information Requirements by Dairy Farmers

Dairy farmers, as the primary producers in the supply chain, should also be given the opportunity to add value to their product by adopting methods of production that satisfy the demands of customers through value added services. Information that agricultural organizations make available to dairy farmers via the organizations' IT systems should give dairy farmers proactive guidance on how to achieve certain objectives on their farms (FAO & IDF, 2011). Farmers obtain information from agricultural organizations, however in rural areas they rely more on radio and television programs for information (Thapa et al., 2020).

The information should be available in a format through which the dairy farmer can engage in the production of milk from any recognized milk-producing cows. Thapa et al. (2020) indicated that farmers require information on quality feeds, transportation, marketing, new technologies, and weather conditions in order to improve decision-making. In addition, farmers require mobile Apps that can provide information on cropping methods, crop management practices, crop protection, and market prices. The information required by dairy farmers should support the production and marketing of safe, quality-assured milk and dairy products (FAO & IDF, 2011). Dairy farmers additionally need information on the following key aspects:

- Animal Health
- Animal Hygiene and Welfare
- Milk Hygiene
- Nutrition (Feed and Water)
- Socio-economic Management and
- The Environment

Dairy farmers need to be constantly aware of the Farm-to-Retail-Price-Spread (FTRPS), which is the difference between what the consumer pays for the product at retail level and the value of the farm product used in that product. The real FTRPS for full cream milk increased from R9.08/l to R9.41/l (+3.68%), during the fourth quarter of 2020 (November 2019–January 2020). The real farm value share decreased, on average, by 6.52%, during the fourth quarter (MilkSA, 2021). Dairy farmers further have to be aware of other commodity prices, including international oil prices that can affect milk transportation costs.

3.3 Agricultural Organizations and Information as a Service

Agricultural organizations must provide information services to customers through their websites, helplines, and the use of other digital technologies (Raza et al., 2020). Raza et al. (2020) indicate that access to the information must be accurate and user-friendly. Agricultural organizations in the dairy industry earn profits by managing and facilitating the supply chain of milk between producers and processors. Agricultural organizations provide information services to farmers, which include advice on herd management, herd feeding and production. The information services include specialist advice on farming practices, data services, such as short-term and long-term weather forecasts and economic indicators. In India, for example, dairy farmers required information on governmental sponsorships, animal reproduction, and veterinary services (Singh & Farhan, 2021).

The way farmers access information on the Internet has changed with the introduction of mobile technologies (Karim et al., 2020). The provision of climate information services has had a positive effect on farmer's income (Mapanje et al., 2020). IaaS for dairy farmers in South Africa is an important information service and agricultural organizations can improve customer satisfaction by providing quality information services for farmers. IaaS is appropriate for agricultural organizations that have various data sources and customers requiring timeous information. IaaS can provide the information needed by dairy farmers in South Africa, to enable them to make the right decisions on an operational level and remain sustainable. Organizations that supply their customers with correct and different kinds of information will build customer loyalty. Dairy farming in South Africa is very price sensitive and therefore information that can help in decision-making will play a very important role in making the right decision at the right time (MilkSA, 2021).

3.4 Extension Services and Self-Service Technology

Agricultural Extension Services (AES), also known as Agricultural Advisory Services, are defined as the organizational structures which support and advise people engaged in agricultural production to solve problems and to obtain information, skills and technologies to improve their livelihoods and general well-being (Birner et al., 2006). Information shared through extension services includes information about current market conditions, local agricultural conditions, agricultural research, agricultural best practices, new farming products, and new farming techniques.

Self-Service Technology (SST) is a technological interface designed to empower customers to produce a service without direct involvement from a service representative. Agriculture organizations use SST to create and disseminate information to customers. SSTs can assist customers in difficult situations, provide more reliable information, provide access to data and support services, and provide flexibility to conduct business without visiting the organization (Simpson, 2014).

4 Research Methodology

The study followed a positivistic research philosophy and the approach was deductive, exploratory, and quantitative. Through convenience sampling, non-probability sampling was used to identify the participants of this study. The IaaS survey required dairy farmers or persons who manage a dairy farm to complete the survey. Dairy farmers in the different provinces of South Africa were the target population. Contact with dairy farmers was achieved through a committee titled the Milk Producers Organisation (MPO), who were approached to assist with the research with access to relevant individuals. The MPO is a platform to which all the dairy farmers in South Africa are affiliated. The MPO serves as the first means of reaching the dairy farmers. The survey was send to 325 farmers registered with the MPO and only five responses were received through the distribution channel of the MPO. The remaining 91 responses were collected by distributing the survey directly to dairy farmers by employees of an international agricultural organization when visiting farmers.

The questionnaire consisted of five sections:

- Biographical details (Age, Gender, Language, Province lived in)
- Technologies used
- Evaluating the importance of information for dairy farmers
- Agricultural organizations information provision and
- The customer satisfaction with an international agricultural service provider

The data from the questionnaires completed by the dairy farmers were captured on QuestionPro and the raw data were exported as a Microsoft Excel file. All unusable or incomplete responses were removed and 96 complete responses were analyzed, which equates to a 21% response rate. The university statistician conducted the statistical analysis using the statistical software package Statistica. Both descriptive and inferential statistics were used to analyze the data. The descriptive statistics were used to describe the profile of the respondents, while inferential statistics were used to make inferences about the three factors identified in the study. Research Ethics approval was obtained.

The following section presents the results of the research, including a discussion on the relevance of the findings.

5 Results and Discussion

A total of 96 questionnaires were completed by dairy farmers in South Africa. The respondents who participated indicated that 96% ($n = 92$) were male and that 4% ($n = 4$) were female (Table 1). All respondents had to be a dairy farmer or dairy farm manager in South Africa. The respondents who participated indicated that 81% speak Afrikaans and that 19% speak English.

Table 1 Biographical details ($n = 96$)

Age		Gender	
18–35	27% ($n = 26$)	Female	4% ($n = 4$)
36–55	52% ($n = 50$)	Male	96% ($n = 92$)
56+	21% ($n = 20$)		
Home language		Province where they farm	
Afrikaans	81% ($n = 78$)	Eastern Cape	52% ($n = 50$)
English	19% ($n = 18$)	Free State	6% ($n = 6$)
		KwaZulu-Natal Province	5% ($n = 5$)
		North West Province	13% ($n = 12$)
		Northern Cape Province	2% ($n = 2$)
		Western Cape	22% ($n = 21$)

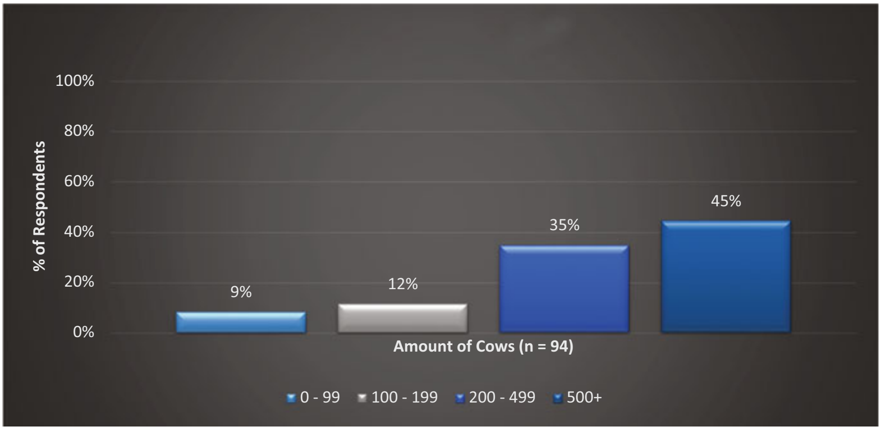

Fig. 1 Size of dairy herd

The respondents in the age group 35 or younger contributed 27%, those in the age group 36–55 contributed 52%, and those who indicated that they were in the age group of over 55 contributed 21% to the total (Table 1). The majority of the respondents are therefore in the age group between 36 and 55 years of age. The age categories younger and older than the age category mentioned have almost an equal number of respondents who participated in the survey. The percentages of respondents in the different age categories are well balanced over the age spectrum.

Geographically the respondents indicated that 52% live in the Eastern Cape Province, 6% indicated that they live in the Free State Province, 22% indicated that they live in the Western Cape Province, 13% indicated that they live in the North West Province, 2% indicated that they live in the Northern Cape Province, and 5% indicated that they live in KwaZulu-Natal Province.

Ninety-four respondents (Fig. 1) indicated that 9% milk 0–99 cows ($n = 8$), 12% indicated that they milk 100–199 cows ($n = 11$), 35% indicated that they milk

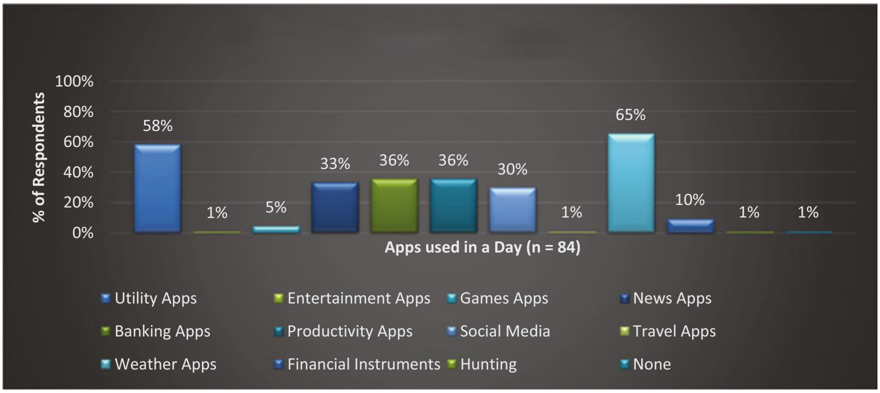

Fig. 2 Apps used in a typical day

200–499 cows (n = 33), and 45% indicated that they milk more than 500 cows (n = 42).

The South African dairy farmers indicated that mobile technologies are the preferred technology for Internet access. Fifty one percent indicated that they access the Internet daily and 85% spend between 1 and 2 h accessing information on the Internet daily. The services used daily include e-mail (85%), banking (89%) and 73% of the dairy farmers indicated that they used the Internet to source information. The results support the proposition that agricultural organizations should actively use the Internet as a medium for information retrieval (Stone & Terblanche, 2012). In addition, 40% used Social Media, specifically Facebook, Twitter, and WhatsApp. Smart phones are the most significant driver of the development of mobile apps (Cortimiglia et al., 2011).

Figure 2 depicts the responses received (n = 84) for the question; *"In a typical day which type of apps do you use on your mobile devices most often?"*. The respondents who participated indicated that 58% used Utility Apps on their mobile devices (n = 49), while 33% indicated that they used News Apps on their mobile devices (n = 28). Thirty-six percent indicated that they used both Banking Apps and Productivity Apps on their mobile devices (n = 30). Thirty percent indicated that they used Social Media Apps on their mobile devices (n = 25), while 65% indicated that they used Weather Apps on their mobile devices (n = 55). Only 10% indicated that they used Financial Instruments on their mobile devices.

Figure 3 depicts the responses received (n = 95) for the question; *"Which sources of information do you find most useful"?* The respondents indicated that 56% found that the *Landbou Weekblad*, an Afrikaans agricultural magazine was a useful source of information (n = 53). Eight percent indicated that they found the Farmers' Weekly a useful source of information (n = 8). Seventy-one percent indicated that they found that the Dairy Mail useful (n = 67). Twenty-one percent indicated that they found Newspapers useful sources of information (n = 20). Twenty-eight percent indicated that they found Television a useful source of information

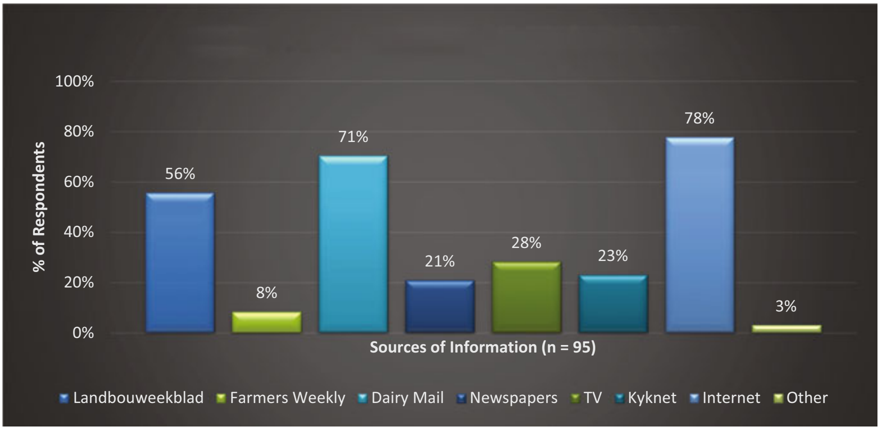

Fig. 3 Most useful sources of information

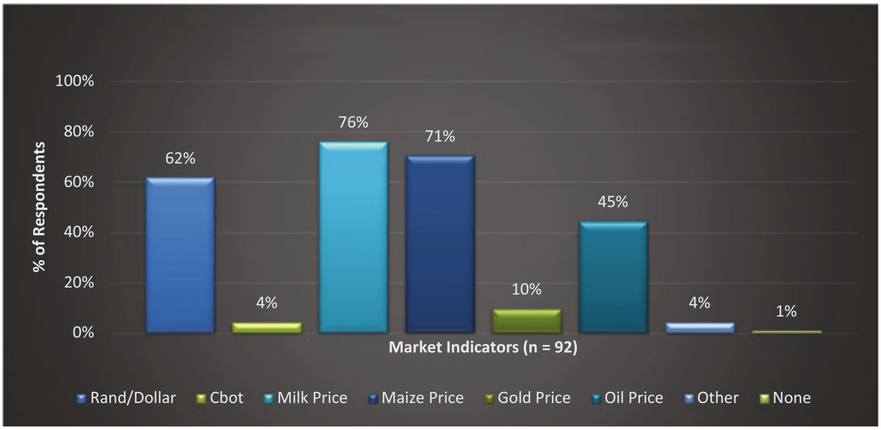

Fig. 4 Types of market indicators researched

($n = 27$). Twenty-three percent indicated that they found Kyknet, an agricultural TV program, a useful source of information ($n = 22$). The majority indicated that they found the Internet a useful source of information (78%; $n = 74$). Therefore, it is important for organizations to have the correct information about the organization on the Internet.

The sources of information were also found effective amongst farmers in Pakistan, specifically television, radio, and agricultural organization's websites (Raza et al., 2020). In India, farmers rely mainly on television as a source of information (Singh & Farhan, 2021). In Nepal, rural farmers relied mainly on radio and television as sources of information (Thapa et al., 2020).

Figure 4 depicts the responses received ($n = 92$) for the question; *"Which market indicators do you research"?* The respondents indicated that 62% ($n = 57$)

researched the Rand/Dollar as a market indicator. Four percent ($n = 4$) indicated that they researched the Cbot as a market indicator. Seventy-six percent ($n = 70$) indicated that they researched the Milk Price as a market indicator and 71% (n = 65) indicated that they researched the Maize Price as a market indicator. Ten percent ($n = 9$) indicated that they researched the Gold Price as a market indicator, while 45% ($n = 41$) indicated that they researched the Oil Price as a market indicator. Four percent ($n = 4$) indicated that they researched other market indicators. The majority of the respondents indicated that they research the Milk Price as a market indicator. Dairy farmers rely on the milk price as a source of income, therefore the daily milk price is an important market indicator for dairy farmers.

The dairy farmers indicated that they have applications on their mobile devices that are typically used by an agricultural community. The respondents who participated indicated that 80% had Utility Apps on their mobile devices; 48% indicated that they had News Apps on their mobile devices; 59% indicated that they had Banking Apps on their mobile devices, and 52% indicated that they had Productivity Apps on their mobile devices. Interestingly, gaming and entertainment type of apps enjoyed little usage, which confirms the use of mobile devices as predominantly business devices. The same pattern of usage emerged when the dairy farmers were asked which apps were most frequently used. Weather apps were the most popular with 65%, followed by Utility apps with 58%, followed by Banking apps with 36% and Productivity apps with 3%.

The information requirements of the respondents ($n = 95$) are indicated in Table 2. The respondents highlighted the importance of weather data (92%), herd management information (95%), and herd feeding information (89%–97%). Most respondents think that the planting dates are important (74%). The information services of agricultural organizations operating in South Africa were evaluated by the respondents. As indicated in Table 2, the respondents were not that satisfied with the information services provision of agricultural organizations in South Africa. Only 55% of the respondents agreed that the agricultural organizations provided accurate market information; that they provided them with personalized information (48%); the information is well presented (58%); the information is easily accessible (58%), and the information is accurate and trustworthy (60%).

The services of an international agricultural organization that operates in South Africa were evaluated by the respondents. The company has operated in South Africa since 2008. The company deals with customers, who purchase animal feed from them. forty nine of the respondents made use of the services of the international agricultural service provider (ASP) operating in South Africa. As indicated in Table 2, the customer satisfaction with the service provider was generally very positive. The respondents agreed that the ASP provided accurate market information (84%); provided them with personalized information (88%); the information is well presented (90%); the information is easily accessible (78%), and the information is accurate and trustworthy (88%).

The Cronbach alpha coefficient values for all the factors (Table 3) indicated good reliability ($\alpha = 0.70$–0.79) or excellent reliability ($\alpha \geq 0.8$), indicating the reliability of the research instrument.

Table 2 Frequency distributions ($n = 95$)

Factors and items	Not important	Neutral	Important
Importance of information for dairy farmers			
Importance of the weather forecast	2 (2%)	6 (6%)	87 (92%)
Importance of the planting date of maize as silage	14 (15%)	9 (9%)	72 (76%)
Importance of seed cultivars	5 (5%)	10 (11%)	80 (84%)
Importance of planting dates for certain pastures	8 (8%)	17 (18%)	70 (74%)
Importance of the correct utilization and management of pastures	9 (9%)	7 (7%)	79 (83%)
Importance of information on total mixed ration (TMR) systems	32 (34%)	22 (23%)	41 (43%)
Information of herd health	1 (1%)	4 (4%)	90 (95%)
Importance of correct feeding for calves	0 (0%)	3 (3%)	92 (97%)
Guidelines on feeding the dairy cow	0 (0%)	5 (5%)	90 (95%)
Guidelines on feeding the dry cow	1 (1%)	9 (9%)	85 (89%)
Information on important dates in the district	18 (19%)	32 (34%)	45 (47%)
Agricultural organizations information provision	*Disagree*	*Neutral*	*Agree*
Agricultural organizations have up-to-date, accurate market information	7 (7%)	36 (38%)	52 (55%)
Agricultural organizations provide me with personalized information	13 (14%)	36 (38%)	46(48%)
Agricultural organization's information is systematically and methodically presented	4 (4%)	36 (38%)	55 (58%)
I trust the information provided by agricultural organizations	9 (9%)	29 (31%)	57 (60%)
Agricultural organizations' information is easily accessible	8 (8%)	32 (34%)	55 (58%)
It appears that agricultural organizations' information is accurate	5 (5%)	33 (35%)	57 (60%)
Customer satisfaction with agricultural service provider (ASP) ($n = 49$)	*Disagree*	*Neutral*	*Agree*
The ASP has up-to-date, accurate market information	0 (0%)	8 (16%)	41 (84%)
The ASP provides me with personalized information	0 (0%)	6 (12%)	43 (88%)
The ASP information is systematically and methodically presented	0 (0%)	5 (10%)	44 (90%)
I trust the information provided by the ASP	0 (0%)	6 (12%)	43 (88%)
The information the ASP provides is easily accessible	2 (4%)	9 (18%)	38 (78%)
The information the ASP provides is accurate	0 (0%)	9 (12%)	43 (88%)

Table 4 depicts that the factors *Importance of information for dairy farmers* ($\mu = 4{,}22$, $t = 15{,}53$, $p < 0.0005$), *Agricultural organizations information provision* ($\mu = 3{,}60$, $t = 2{,}92$, $p = 0.004$), and *Customer satisfaction with agricultural service provider* ($\mu = 4{,}23$, $t = 10{,}91$, $p < 0.0005$) all received a positive mean score with

Table 3 Cronbach's alpha coefficients for the factors

Factor	*n*	Mean	S. D.	Cronbach's alphas	Reliability
Importance of information for dairy farmers	95	4,22	0,51	0.72	Good
Agricultural organizations information provision	95	3,60	0,66	0.96	Excellent
Customer satisfaction with agricultural service provider	49	4,23	0,53	0.97	Excellent

Table 4 One-sample t-Test

Factors	*n*	Mean	S. D.	d. f.	*t*-value	*p* ($\mu \neq 3.40$)	Cohen's *d*
Importance of information for dairy farmers	95	4.22	0.51	94	15.53	<0.0005	1.59 (large)
Agricultural organizations information provision	95	3.60	0.66	94	2.92	0.004	0.30 (small)
Customer satisfaction with agricultural service provider	49	4.23	0.53	48	10.91	<0.0005	1.56 (large)

significant statistical significance ($p < 0.0005$) and a small to large practical significance. The results indicate the importance of IaaS for dairy farmers in South Africa and agricultural organizations' information provision.

The results presented in this section highlighted the different Apps used by the respondents, the most popular included Utility Apps and Weather Apps. Eighty-five percent of the respondents spend 1–2 h a day on the Internet. Agricultural magazines are regarded as useful source of information, as well as market indicators. In Table 2, they highlighted the importance of weather data (92%), herd management and health information (95%), and herd feeding information (95%). Agriculture organizations wanting to provide IaaS need to take these requirements into consideration. Based on these findings, an IaaS communications framework for dairy farmers is proposed in the next section.

6 Proposed IaaS Communication Framework for Dairy Farmers

The proposed Communication Framework for Dairy Farmers is presented in Fig. 5. The framework adopts a top-down approach that starts at the South African Agricultural Environment and works its way down until the component on information required is reached. The information required feeds back to the beginning where the process starts all over again at the South African Agriculture Environment. The different components of the framework are connected to each other and are directly

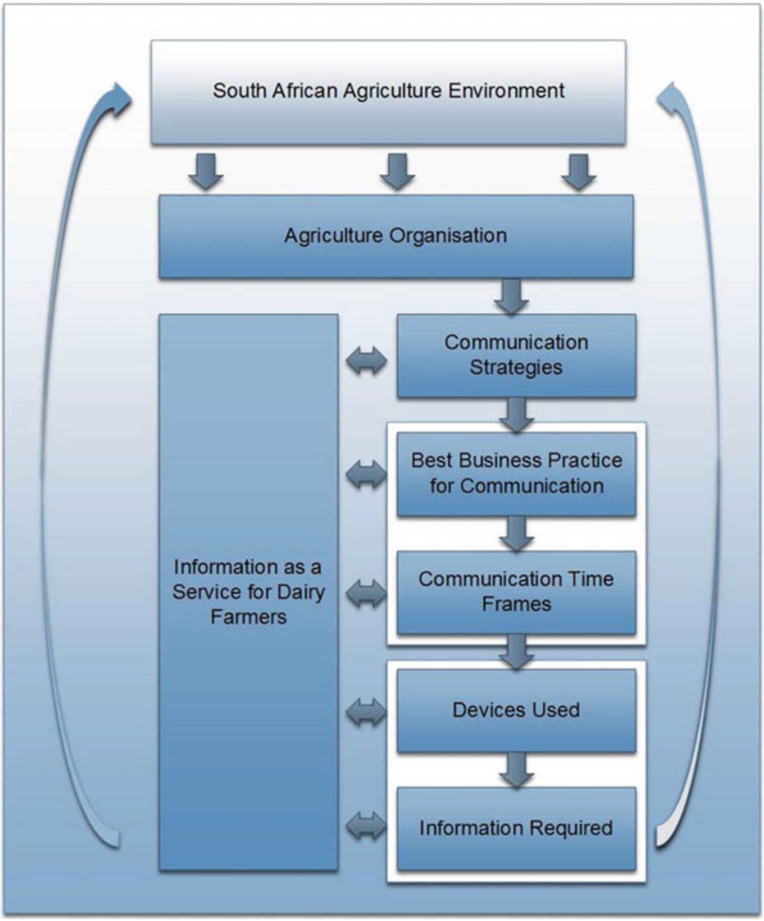

Fig. 5 IaaS communication framework for dairy farmers (Author's own creation)

influenced by any form of change made to the IaaS for Dairy Farmers. Therefore, it is clear that no section of the framework can be viewed in isolation.

The heart of the proposed IaaS Communication Framework for Dairy Farmers is the South African Agriculture Environment. The Information that dairy farmers finally require to make the correct decisions in their farming operations stems from what is allowed by the South African Agriculture Environment. The second section is the Agriculture organization, as agriculture organizations need to operate in the South African Agriculture Environment. The agriculture organizations have their own communication strategies that they follow to communicate with their customers. The communication strategy component of an agricultural organization has an internal- and external environment. The internal environment consists of two sections, namely, Best Business Practice for Communication and Communication Time Frames. The external environment consists of two sections, namely, Devices Used and Information Required. The information flows from these components to the Information as a Service for Dairy Farmers component and back to these components. The IaaS component in turn feeds information back to the South African Agriculture Environment. The *Information Required* component feeds information back to the beginning namely: the South African Agriculture Environment.

The following sub-sections discuss each of the components of the proposed IaaS Communication Framework for Dairy Farmers in more detail:

- **South African Agriculture Environment**

  The South African Agriculture Environment is at the heart of the framework. The South African Agriculture Environment identifies the measurable goals and objectives of the agricultural organization. The South African Agriculture Environment will be influenced by the Political-, Economical-, Social-, Technological-, Legal-, and Environmental situation. The commitment of top management of an agricultural organization will be incorporated at this level.
- **Agricultural Organization**

  The second component of the IaaS Communication Framework for Dairy Farmers is the agricultural organization. The agricultural organization will identify the communication strategy that the organization will follow. The communication strategy will remain in the boundaries set by the South African Agricultural Environment. The agricultural organization can be any organization that is doing business with a dairy farmer in the agricultural field.
- **Communication Strategies**

  The third component of the IaaS Communication Framework for Dairy Farmers is the communication strategies. The communication strategies that an agricultural organization will follow will depend on the type of communication technologies that the agricultural organization uses. Dairy farmers may belong to a Self-Help Group through which the agricultural organization can communicate with the dairy farmer. The information that organizations shared with their customers was very limited in the past. This has changed with the availability of IT systems that organizations use. Agricultural organizations normally use their IT systems and applications to communicate with dairy farmers, using their mobile devices.

  The strategy that an organization chooses to use must be able to interact with the technology that is available to the dairy farmer. The communication strategy used by the agricultural organization to communicate with the dairy farmer will be made available through the IaaS. The IaaS will need to be updated with the most recent communication strategies that an agricultural organization may use.
- **Best Business Practice for Communication**

  The fourth component of the IaaS Communication Framework for Dairy Farmers is the Best Business Practice for Communication. The Best Business Practice for Communication is an internal environment of the communication strategy that an organization may follow. The best way to communicate with dairy farmers will depend on the type of media, including social media that an organization chooses to use. The social media will depend on the type of technology that organizations and dairy farmers use to access information on the Internet. The social media used by organizations to communicate with dairy farmers will depend on the time frames that the organization chooses to communicate with the dairy farmer. Facebook may be one of the more popular social media sites because of the groups that can be created by either the organization or the dairy farmer.

The best business practice for communication used by an agricultural organization to communicate with dairy farmers will be made available through the IaaS. The IaaS will need to be updated with the most recent, best business practices for communication that an agricultural organization may use.

- **Communication Time Frames**

  The fifth component of the IaaS Communication Framework for Dairy Farmers is communication time frames. Communication time frames are part of the internal environment that organizations use to communicate with dairy farmers. The communication time frames that agricultural organizations use to communicate with dairy farmers will depend on the media that agricultural organizations choose to use. The most convenient communication time frame will be the one that is the most suitable for dairy farmers. The communication time frames used by the agricultural organization to communicate with the dairy farmer will be made available through the IaaS. IaaS will need to be updated with the most recent communication time frames that an agricultural organization may use.

- **Devices Used**

  The sixth component of the Communication Framework for Dairy Farmers is the devices used. The devices used is part of the external environment that organizations use to communicate with dairy farmers. The external environment that is not managed by an organization but it is influenced by external factors. The technology used to access information by dairy farmers can vary from a mobile phone to a tablet. The devices used will depend on the technology that dairy farmers feel comfortable with. Dairy farmers have adopted the smart phone that they can use to do virtually all their business. The devices used by an agricultural organization to communicate with dairy farmers will be made available through the IaaS. The IaaS will need to be updated with the most recent devices used by agricultural organizations.

- **Information Required**

  The seventh component of the IaaS Communication Framework for Dairy Farmers is information required. The information required is part of the external environment that organizations use to communicate with dairy farmers. The information that agricultural organizations provide to dairy farmers needs to give them the correct guidance on performing good farming practices in order to produce safe, quality milk. Dairy farmers can adopt any of these guidelines depending on their own situation. Dairy farmers will not be legally bound to these guidelines, but they will ensure that dairy farmers make the correct decisions for their farming enterprise. Dairy farmers require information on the following topics: Animal Health, Milk Hygiene, Nutrition (Feed and Water), Animal Welfare, The Environment, and Socio-economic Management.

The information required by an agricultural organization to communicate with the dairy farmer will be made available through the IaaS. The IaaS will need to be updated with the most recent information required by dairy farmers. The IaaS for Dairy Farmers and the information required by dairy farmers feeds back to the South African Agricultural Environment, where the process starts again from the beginning.

7 Conclusions, Limitations, and Recommendations

The application of advanced digital technologies such as AI and the IoTs has the potential of transforming the agricultural sector (Aguera et al., 2020). Dairy farmers having access to digitally stored data for use in automated applications and information can improve farm management and decision-making (Akbar et al., 2020). The objective of the chapter was to explore the information requirements of dairy farmers, determine the customer satisfaction with information services provided by agricultural organizations, and to provide an IaaS communication framework for dairy farmers. The purpose of the research is to inform South African agricultural organizations, implementing or updating communication strategies for IaaS, of the extent and manner in which the Internet and mobile technology are used in the dairy farming community.

The Internet profile of dairy farmers indicated that they use the Internet predominantly for business related activities. The majority of the respondents indicated they use mobile devices to access the Internet. A significant acceptance of the technology is visible amongst the dairy farmers in South Africa. This research study supports the findings of Thapa et al. (2020), as 73% of the dairy farmers indicated that they used the Internet to source information, specifically weather information, farm management, and market related information. Therefore, it is important that agricultural organizations actively include the Internet as a medium for information dissemination to dairy farmers.

The technologies used by an agricultural organization to communicate with dairy farmers will incorporate IaaS. The proposed framework on IaaS for Dairy Farmers will help agricultural organizations to supply dairy farmers with the right information at the right time. Farmers could thus access the information on a daily basis, which will assist dairy farmers to become more sustainable and implement and maintain sustainable farming practices.

Analyzing the applications installed by dairy farmers on their mobile devices confirms the notion that they are using mobile technology primarily for accessing the Internet for business purposes. Extending on research done by Stone and Terblanche (2012) and Jones et al. (2010), which emphasized the importance of extension services, this research found that agricultural organizations could enhance communication strategies and services through the effective use of mobile technologies in the availability of IaaS for Dairy Farmers.

The respondents indicated the information services they required related to the importance of weather data (92%) and herd management information (95%) and herd feeding information (97%). The respondents were generally not satisfied with the information services provided by agricultural organizations in South Africa. The agricultural organizations need to take cognizance of these results and determine the dairy farmer information requirements and implement suitable digital technologies to provide the services to farmers. 49 respondents that made use of the international agricultural organization operating in South Africa were satisfied with the information service provision.

The proposed IaaS Communication Framework (Fig. 5) can be used by agricultural organizations to provide IaaS to farmers. The limitation of the research study is the small sample size, limiting the statistical analysis. Future research will investigate the implementation of the proposed framework and the evaluation of an IaaS application for dairy farmers in South Africa.

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Understanding the Agricultural Input Information Needs and Seeking Behavior of Small-Scale Farmers: A Case of Koulikoro Region in Mali

Macire Kante and Patrick Ndayizigamiye

Abstract Many developing countries have put in place interventions to help small-scale farmers to increase their agricultural productivity. Some of these interventions include the use of Information and Communication Technology tools by extension services to disseminate agricultural input information. However, to date, there is still a limited understanding of the agricultural information needs and seeking behavior of these farmers. Such understanding is needed in order to devise adequate ICT-driven interventions that are in sync with the information needs and seeking behavior of the farmers. Hence, this study investigated farmer's agricultural input information needs and their information-seeking behavior in the context of Mali. The study adopted the Information-Seeking Task framework as the guiding theoretical lens. Data, gathered from 100 respondents, were analyzed using the Partial Least Square Structural Equation Modeling. The results revealed that there are five farmer's agricultural input information needs, namely calendar planning; planting; water, fertilizer, and pest management, and input provision. Furthermore, the findings showed that farmers seeking agricultural input information formally, that is, through mobile phone satisfied their information needs more than those seeking it informally through their peers. The findings suggest that farmer's extension services should pay more attention to these results when devising their interventions.

Keywords Agricultural information · Information needs · Farm inputs · Seeking behavior · PLS-SEM · Mali

1 Introduction

Mali is a developing country with no access to the sea situated in West Africa. The surface area of the country is 1,241,238 km^2 (Simpara et al., 2012), with a population of 19,035,144 (Worldometers, 2018). About 69.9% of the Malian population

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(15 years and above) is illiterate (INSTAT, 2015). In Mali, small-scale farmers dominate the agricultural production (68%) (Aparisi & Balie, 2013), which represents more than 35% of the Gross Domestic Product (GDP) and 80% of livelihoods (FAO, 2017). The country is considered as food insecure, as 37.7% of households have difficulties nourishing themselves (INSTAT, 2014) due to low use of agricultural inputs (consumable inputs) by small-scale farmers (IFDC, 2004; Kante et al. 2017a, b, c; E T Lwoga et al., 2011) amongst other factors. Consequently, there is an agreement that agricultural productivity should be increased (Isaya et al., 2018; Kameswari et al., 2011; Kante et al. 2017a, b, cs). This could be achieved by using modern agricultural inputs, new technologies and practices that enable farmers to improve their yield while reducing environmental impacts (Van Campenhout et al., 2017). Increasing agricultural productivity of small-scale farmers is one of the main objectives of many developing countries (Kante et al. 2017a, b, c; Quandt et al., 2020). Information and Communication Technologies (ICTs) could be used to achieve such an increase by disseminating agricultural input information to small-scale farmers (Barakabitze et al., 2015). However, agricultural extension officers should firstly understand the agricultural input information needed by these farmers as well as their information-seeking behavior. Such understanding is crucial to devising interventions to make the needed information accessible to farmers, and also to develop demand-led extension services and advisory systems (Edda Tandi Lwoga et al., 2010). Information needs refer to the information that enable people to keep doing their daily business (Chimah & Udo, 2015). In the case of small-scale farmers, it refers to the information about agricultural inputs needed to increase farmer's productivity.

Farmer's information-seeking behavior should be assessed to determine the ICT-enabled medium that could be used to convey the information that they need. Information-seeking behavior is described as the predilections and ways illustrated by people while looking out for information (Chimah & Udo, 2015). In this case, it is the tendencies and approaches that small-scale farmers exhibit while seeking agricultural input information. The process that small-scale farmers follow when seeking information tends to be purposive in nature and an outcome of the need to satisfy some objective(s) (Edda Tandi Lwoga et al., 2010). This process is displayed through the interaction with people, either face-to-face or electronically.

Information needs can be ascertained by the information seeker or by an information expert on behalf of the information seeker (Chimah & Udo, 2015; Edda Tandi Lwoga, 2010; Msoffe & Ngulube, 2016; Peter O Siyao, 2012b). Moreover, there may be a need for the information seeker (small-scale farmer) and the information expert (researcher/practitioner) to work together toward disentangling and establishing the actual information needs. Therefore, in the context of Mali, the objectives of this study were to

1. Establish farmer's agricultural input information needs and their information-seeking behavior.
2. Determine the effect of farmer's agricultural input information needs on their agricultural input information-seeking behavior.

3. Determine the effect of farmer's agricultural input information-seeking behavior on satisfying their agricultural input information needs.

2 Literature Review

This section reviews the literature concerning farmer's agricultural input information needs and information-seeking behavior.

2.1 Small-Scale Farmers' Agricultural Input Information Needs

Small-scale farmer's agricultural input information needs have been reported in developing countries. For instance, scholars argued that agricultural input information refers to information on crop planning, i.e., better information on higher crop yields and seed varieties, buying seeds, i.e., identifying the best time to plant and source inputs, planting, i.e., using better fertilizer and applying better technologies (Aker, 2011; Kante et al., 2017a, b, c). This definition was later enhanced by Siyao (Aker et al., 2016) who reported that agricultural inputs are mostly needed in the pre-cultivation and cultivation stages. Hence, farmer's information needs on agricultural inputs in these two stages are:

(a) *Pre-cultivation*
   1. Crop selection
   2. Land selection
   3. Calendar planning

(b) *Cultivation*
   4. Land preparation
   5. Access to credit
   6. Input provision
   7. Planting
   8. Weather, fertilizer, pest management

The difference in the elements that constitute agricultural input information is related to farmer's agricultural information needs and their location. For instance, in Tanzania, small-scale farmer's agricultural input information needs include controlling plants' diseases of, control of pests, access to credit, the control of animal's diseases and irrigation practices (Edda Tandi Lwoga, 2010). In addition, these information needs vary from district to district in Tanzania. The same observation was made in Lesotho and India (Edda Tandi Lwoga et al., 2010; Siyao & Onauphoo, 2010). Hence, farmer's agricultural input information needs vary according to their location, amongst other factors.

On the other hand, ICT-based agricultural input information service providers often aim to provide all the information and assistance that farmers could need. This leads to complex, costly, unworkable, and unsustainable design of their interventions (Vota, 2018). For example, projects aiming to supply extension services with information sometimes run into difficulties in sourcing the appropriate content (Wayan Vota, 2018). The quality of the information provided affects farmer's satisfaction. A better way would be to start by disseminating little information to address a core problem and upgrade and scale-up services when the pilot phase is successful (Saleh & Lasisi, 2011). In the same vein, there is a need to determine the agricultural input information that most farmers need. This information could then be the starting point for any ICT project that aims to support agricultural extension services.

2.2 Small-Scale Farmer's Agricultural Information Sources and Behavior

Information sources can be categorized as formal when the information is communicated through ICTs (TV, mobile phone, radio) and informal when the information emanates from peers (including friends and family members) (Edda Tandi Lwoga et al., 2010). Hence, the information-seeking behavior can be categorized as formal or informal depending on the source of the information. Various studies (Edda Tandi Lwoga et al., 2010; Msoffe & Ngulube, 2016; Saleh & Lasisi, 2011) have reported the needed agricultural information and information-seeking behavior of farmers in developing countries. These studies report radio broadcasts, television broadcasts, and posters as the most preferred ICTs channels for agricultural input information for farmers. Other channels (sources) of agricultural input information and by far the most preferred are neighbors and friend (Lwoga et al., 2010, 2011). However, in Mali, small-scale farmers' preferred agricultural input information sources have not been investigated.

On the other hand, mobile phones are the best way of addressing the gaps on the sources of farmer's agricultural input information. For instance, it has been observed that cell phones are the only form of ICTs used by the majority of small-scale farmers in Africa (Bertolini, 2004). This means that the mobile phone is the best tool to reach farmers with agricultural input information. However, it is not clear whether a mobile phone is the preferred source for farmers to satisfy their agricultural input information needs. New ICT media (such as mobile phones) provide several key benefits compared to traditional ICT media (Bwalya et al., 2012). A mobile phone can improve agricultural (input) information flow amongst farmers and thus connecting them. This also means that a mobile phone can act as a driving factor of farmer's peer influence. Moreover, illiteracy does not constitute a challenge for farmers to get agricultural input information by means of mobile phones (Asenso-Okyere & Mekonnen, 2012).

While the benefits of mobile phone use over the traditional ICT media are recognized, they are not without challenges (Asenso-Okyere & Mekonnen, 2012). Some factors may still restrain the information seeking, which may result in not obtaining useful information (Edda Tandi Lwoga et al., 2010). Factors such as information quality (content), system quality (convenience, usability, reliability), and service quality (support) were reported in Tanzania as affecting the use of mobile phones (Msoffe & Ngulube, 2016). In Mali, three factors were reported: the appropriateness of presentation, relevancy, and completeness of the provided information (Kante et al. 2017ba, b, c). The study conducted in Mali proposed an ICT-based agricultural information adoption model for farmers in the region of Sikasso. Although the study had been conducted in Mali, there is a need to re-assess these factors. This need arises from the fact that regular studies need to be conducted to ascertain farmer's information needs to accommodate changes in their environment (Edda Tandi Lwoga et al., 2010).

2.3 Conceptual Framework

Many theories and models have been proposed to investigate the satisfaction of farmer's information needs (Edda Tandi Lwoga et al., 2010; Msoffe & Ngulube, 2016; Sanga et al., 2013; Srivatsan et al., 2009). The information-seeking task model has been applied by various scholars to understand the information needs and the information-seeking behavior of farmers (Hyldegård, 2009; Li & Belkin, 2008, 2010). In this study, we argue that the information-seeking task model (Srivatsan et al., 2009) is more suitable for this study than any other model. This stems from the fact that the information-seeking task model focuses on the satisfaction of an entire information need taking into consideration channels and sources (Isaya et al., 2018). Agricultural input information could, for instance, be information on credit or information on where to buy fertilizers. The source of the information could be a mobile phone or friends (then the seeking behavior would be formal or informal). Furthermore, the model could determine which information type satisfies the farmers more. It can also determine which source of information is the most preferred by farmers. The Information-Seeking Task framework (Fig. 1) was adopted in this study and is adapted and illustrated in the context of this study in Fig. 2.

We formulated our conceptual framework (see Fig. 2) based on the identified agricultural input information needs outlined in Sect 2.1 and the Information-Seeking Task framework presented in Fig. 1. The agricultural information needs are the independent variables, whilst the seeking behavior, i.e. formal or informal and need satisfaction are the dependent variables.

3 Materials and Methods

This study was conducted using the positivist philosophy. This philosophy in contrast to the interpretivism philosophy rejects the notion of consciousness and humanly created meanings (Mahamadou Kante & Kante, 2020). A research

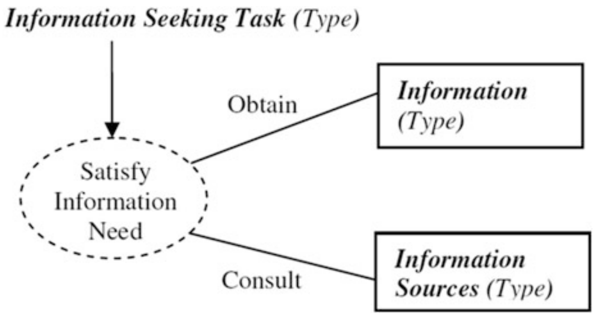

Fig. 1 Information-seeking task framework. Source: Srivatsan et al. (2009)

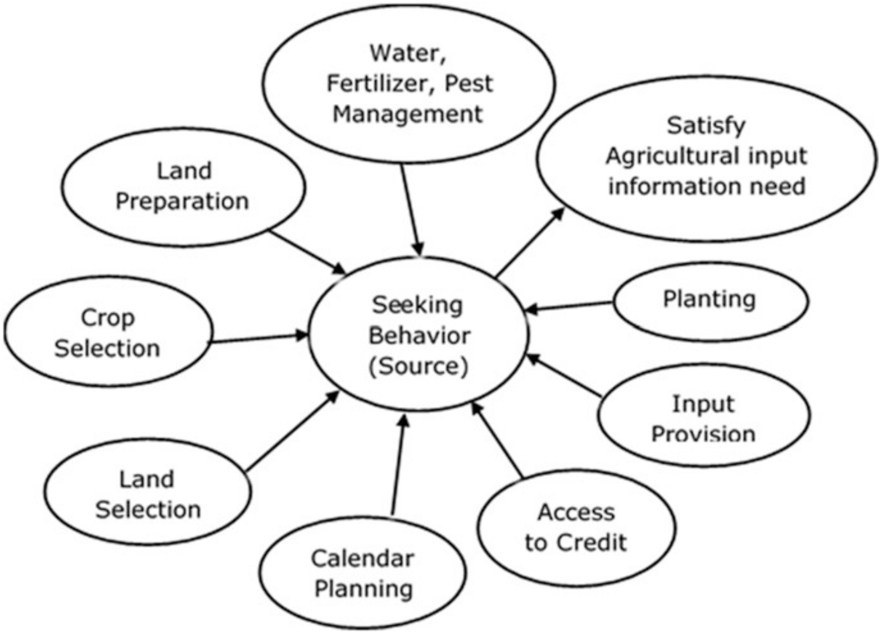

Fig. 2 Conceptual framework of the study

instrument was designed following a deductive approach and based on the above conceptual framework.

3.1 Design

Figure 3 below displays the steps that were taken to arrive at the conclusion and recommendations of this study. This figure provides the steps that were followed to arrive at the conclusion of the study. Firstly, we undertook a literature review, which looked at empirical and theoretical constructs. That resulted to the conceptual

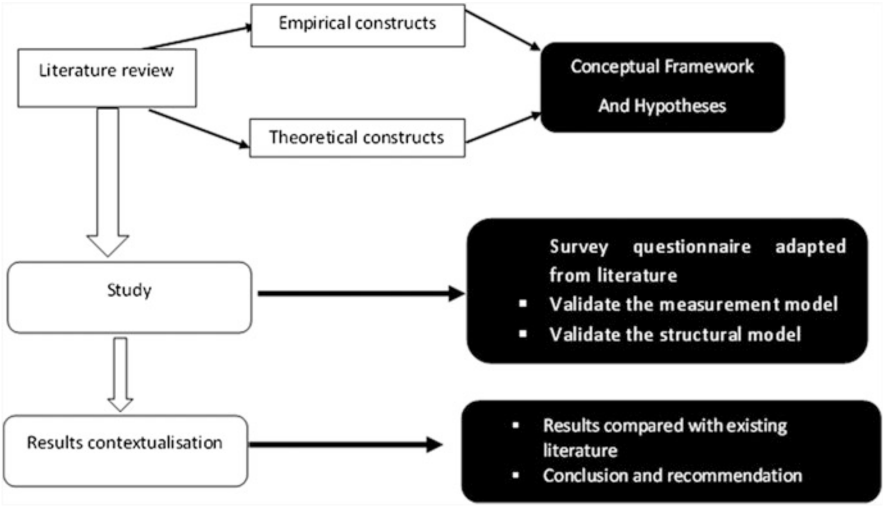

Fig. 3 Research design of the study

framework with supporting hypotheses. Secondly, the study was conducted using a survey questionnaire to collect data and to validate the measurement model as well as the structural model. Thirdly and lastly, we contextualized the results by mapping them against the available literature in the field. That led to the conclusion and some recommendations.

3.2 Study Area and Sampling

This study was conducted in the region of Koulikoro, Mali. Koulikoro had a population of 2,422,108 (RGPH, 2013) of whom 87.5% relied on agricultural activities (GERAD, 2010). The region was purposively selected, as it uses more agricultural input (*Phosphate Naturel de Tilemsim*–Tilemsim natural phosphate—PNT-) than any other region in Mali (CPS/SDR, 2016). This makes the region's farmers perhaps the most frequent users of the subsided *Phosphate Naturel de Tilemsim* (PNT) from the Mali's government and hence, one of the reasons for choosing this region. Furthermore, the region of Koulikoro is the second most industrialized region of Mali. In 2009, the region had 59 industrial units (GERAD, 2010). The district of Kati (circle) had 60.3% of the industrial units, while the district of Koulikoro accounted for 20.7% of the regional industries. Industrial presence often goes in tandem with the rate of ICT or mobile phone penetration (Diallo, 2013). Thus, the districts of Kati and Koulikoro in the Koulikoro region were selected as the study sites.

We gathered data from 100 respondents (farmers) who were randomly selected. A sample size of 150–200 is the recommended size for any study using PLS-SEM technique (Kline, 2013). However, this was contrasted by other scholars who argued that small sample size such as 21 (Garson, 2016), 30 (Hair et al., 2011), and 100 (Kante et al., 2018) is not an issue for PLS-SEM. Thus, our sample size of 100 respondents was adequate to draw statistically sound conclusions.

3.3 Data Collection and Analysis

A survey questionnaire, adapted from (Aker et al., 2016; Heeks & Molla, 2009b; Macire Kante et al., 2019; Kante et al. 2017a, b, c; Siyao & Onauphoo, 2010; Villar, 2009) (see Appendix (Table 6)), and consisting of 29 items was administered to the respondents (farmers). Randomly selected farmers filled the questionnaire, which was then returned to enumerators. The enumerators read out statements from the questionnaire to some respondents who could not fill it. The items in the questionnaire were formulated based on a 5-point Likert scale: 1 = Always, 2 = Frequently, 3 = Occasionally, 4 = Rarely, and 5 = Never. For the information needs items, we relied on the CARTA criteria (Heeks & Molla, 2009a). These criteria are the completeness of the information; accuracy; relevancy; timeliness and appropriateness of presentation. More details on these criteria are found in Appendix (Table 6).

IBM SPSS v20 was used to analyze the data for frequency and descriptive analysis. We further used the SMARTPLS 3.2.8 software for the PLS-SEM analysis.

A conceptual framework needs to be evaluated by developing metrics and measuring the framework's constructs according to those metrics. Several techniques such as regression and Structural Equation Modeling allow researchers to evaluate their conceptual models. Urbach and Ahlemann (2010) argue that SEM allows researchers to respond to a set of the interrelated research questions in a single, systematic, and comprehensive analysis. This is achieved by modeling the relationship between multiple independent and dependent constructs simultaneously. There are two SEM techniques, namely the Covariance Based and Partial Least Square (PLS). This study employed PLS-SEM as it is the most recommended and used approach in Information System Research (Evermann & Tate, 2014; Kante et al., 2018). It is also appropriate to the study as the study's sample size is relatively small (about 100) (Garson, 2016).

PLS-SEM models are path models that depict variables that may be effects of others while still being input for other variables in the hypothesized causal sequence (Kante et al., 2018). The measurement (or outer) model determines the meaning of the (latent) variables (Garson, 2016) while the hypotheses (causal links in the model) are represented by the structural (or inner) model. The criteria for the model assessment are displayed below in Table 1.

Table 1 PLS-SEM assessment criteria

Validity type	Criterion	Description
Indicator reliability	Indicator loading >600	They represent the absolute contribution of the item to the definition of its construct
Internal consistency reliability	Cronbach's α >0.6	Measures the degree to which responses are consistent across the items within a measure
Internal consistency reliability	Composite reliability >0.6	Attempts to measure the sum of the factor loadings of a latent variable relative to the sum of the factor loadings plus error variance
Content validity	Average variance extracted (AVE) >0.5	The degree to which individual items reflect a construct converge in comparison to items measuring different constructs
Discriminant validity	Heterotrait-Monotrait ratio (HTMT) <1	Discriminant validity should be assessed by the Heterotrait-Monotrait ratio (HTMT).
Model predictability	Predictive relevance Q^2 >0.05	By systematically assuming that a certain number of cases are missing from the sample, the model parameters are estimated and used to predict the omitted values
Model validity	R^2 >0.100	Coefficient of determination
Model validity	Critical t-values of path coefficients for a two-tailed test are 1.65 (significance level = 10%), 1.96 (significance level = 5%), and 2.58 (significance level = 1%)	Structural path coefficients are the path weights connecting the factors

Source: Macire Kante et al. (2018), Sarstedt and Cheah (2019)

4 Results and Discussion

We screened the data and found that three questionnaires were partially filled and therefore were not included in the analysis. Moreover, low responses were detected in two other questionnaires. Hence, our dataset consisted of 95 valid questionnaires out of the 100 that were initially collected. The mean-replacement technique was used to identify and address the missing values within the valid responses.

4.1 Respondent's Demographics and Channels Used for Seeking Farm Input Information

Table 2 presents an overview of the respondent's demographics in terms of gender, age, and seeking behavior for farm input information. The table reveals that about

Table 2 Respondent distribution per gender and age range

Gender			Seeking farm input information		Total
			Yes	No	
Male	Age range	<18 years	0	1	1
		18–28 years	4	2	6
		29–38 years	9	3	12
		39–48 years	13	4	17
		49–58 years	11	5	16
		59–68 years	14	3	17
	Total		51	18	69
Female	Age range	18–28 years	2	4	6
		29–38 years	3	7	10
		39–48 years	3	2	5
		49–58 years	4	0	4
		59–68 years	1	0	1
	Total		13	13	26
Total	Age range	<18 years	0	1	1
		18–28 years	6	6	12
		29–38 years	12	10	22
		39–48 years	16	6	22
		49–58 years	15	5	20
		59–68 years	15	3	18
	Total		64	31	95

73% of the respondents were male farmers. A closer inspection of the data in the table shows that about 67% of the respondents searched for farm input information. Amongst those searching for information, almost 80% were male farmers. This finding is in contrast with another study (Kante et al. 2017ba, b, c) which showed that about 75% of farmers seeking farm input information through a mobile phone in the Sikasso region of Mali were females. In this study, we collected data on the channels that were being used to seek farm input information. Our findings revealed that about 71% of the respondents sought farm input information using a mobile phone (also using the radio broadcasting feature embedded in their phones). Amongst them, only 25% were females.

In Tanzania, radio broadcasting is still the most appropriate communication technology available to most people, including women and youth, particularly in rural communities (Peter O Siyao, 2012a). In the context of Mali, the use of the radio broadcasting feature embedded in mobile phones is still the main reported communication technology available to most farmers as per our results.

4.2 *Farmer's Agricultural Input Information Needs and Their Agricultural Input Information-Seeking Behavior*

The conceptual framework depicted in Fig. 2 was subjected to the PLS-SEM analysis which comprises two subsequent models, namely the measurement model and the structural model. The first subsequent model is concerned with the validity of the constructs used in a model. With regard to that subsequent model (measurement model), we assessed the construct validity of the factors within the conceptual framework (see Fig. 2). If the validity of the factors within a construct is established, it means the construct fully fits the model and is unique. In the context of the study, factors that have passed this assessment are indeed the agricultural information needs of farmers.

The first criterion assessed was the convergent validity as reported in Table 3. Table 3 shows that the Average Variance Extracted (AVE) values of access to credit, land selection, crop selection, and land preparation factors are below the cut-off of 0.50. Consequently, they were removed from the model.

The second criterion assessed was the divergent validity. The results presented in Table 4 show that all the factors have passed the test, as all the scores are below 1.

As the convergent and divergent validity of (1) calendar planning, (2) planting, (3) seeking behavior (source), (4) water, fertilizer, pest management, and (5) input provision were established, one can deduce that these factors are the agricultural input information needs of farmers. These findings mean that the extension services should pay more attention to these factors in the region of Koulikoro. Moreover, interventions could be devised to encourage extension officers and farmers to use mobile phone in the dissemination/getting agricultural input information. For instance, the national agricultural extension services could design training sessions for farmers and extension officers using SMS and call-in services on the identified agricultural input information needs. The "sources of information" construct

Table 3 Convergent validity

Construct	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)
Access Credit[a]	0.898	0.579	**0.278**
Calendar planning	0.903	0.925	0.712
Land selection[a]	0.919	0.000	**0.074**
Planting	0.881	0.903	0.652
Satisfy_agricultural_input_information_need	0.814	0.864	0.683
Seeking behavior (source)	0.755	0.811	0.466
Water, fertilizer, pest management	0.897	0.917	0.690
Crop selection[a]	0.811	0.072	**0.162**
Input provision	0.898	0.916	0.685
Land preparation[a]	0.787	0.672	**0.332**

[a]The AVE is below the threshold value of 0.5 and was consequently removed from the model

Table 4 HTMT criterion for divergent validity

	AC	CP	LS	P	Satis	Source	WFPM	CS	IP
Access credit (AC)									
Calendar planning (CP)	0.12								
Land selection (LS)	0.21	0.52							
Planting (P)	0.20	0.36	0.19						
Satisfy_agricultural_input_information_need (Satis)	0.08	0.45	0.30	0.47					
Seeking behavior (SB) (source)	0.10	0.14	0.12	0.20	0.18				
Water_ fertilizer_ pest_ management (WFPM)	0.24	0.30	0.33	0.40	0.47	0.17			
Crop selection (CS)	0.22	0.25	0.63	0.28	0.25	0.18	0.31		
Input provision (IP)	0.12	0.17	0.15	0.58	0.43	0.11	0.55	0.29	
Land preparation	0.16	0.49	0.41	0.54	0.46	0.16	0.21	0.29	0.21

comprises the following items: mobile phones, television, extension officers, and peers. As the sources construct validity was established (passing convergent and divergent validity criteria), therefore, it can be deduced that mobile phones, television, extension officers, and peers are the channels that farmers use to satisfy their agricultural input information. Nonetheless, we need to know which channel mostly satisfies farmer's agricultural input information needs.

4.3 Effects of Farmer's Agricultural Input Information Needs on Their Agricultural Input Information-Seeking Behavior

As per the results in Table 3, the agricultural information needs of farmers are calendar planning, planting, water, fertilizer, pest management, and input provision. These agricultural input information needs explain 27.1% of the variance of agricultural input information-seeking behavior as shown in Fig. 3. Furthermore, in the model depicted in Fig. 3, calendar planning has the highest effect size (f^2) with a value of 0.15. A value of 0.02 represents a "small" effect size, 0.15 represents a "medium" effect, and 0.35 represents a "high" effect size (Garson, 2016). Hence, in our model, calendar planning (0.15) and input provision (0.12) have medium effect sizes. The f^2 value of planting (0.07), water_ fertilizer_ pest management (WFPM) (0.07) is higher than the 0.02 but cannot be quantified as medium, as their f^2 value is less than 0.15. Thus, planting and WFPM have a small effect size on information-seeking behavior.

These results are consistent with the literature. For instance, Chime and Anyidoho (Chime & Anyidoho, 2019) reported that in Ghana, farmers needed information on pest and diseases control. Another study in Ghana (Acheampong et al., 2017) reported pesticide and fertilizer use as well as weed and diseases control measures as farmer's information needs. Similar results were reported in Tanzania (Msoffe & Ngulube, 2016). Nevertheless, these studies did not use any modeling technique that could depict the effect size of the reported information needs.

4.4 Effects of Agricultural Input Information-Seeking Behavior on Satisfying Farmers' Agricultural Input Information Needs

The validated model was weighed against each one of the information-seeking channels (extension officers, radio, mobile phone, TV, and peers). For each weighing, we looked at the coefficient of determination (R^2). The weighed model that explained the dependent factors (seeking behavior and satisfaction) more was then chosen as the most suitable information-seeking channel for farmers which

Table 5 Model results per source of information

Weighting factor (source–channel)	Coefficient of determination (R^2)	
	Seeking behavior (%)	Satisfaction (%)
Extension officer	12	8
Peers	62	10
TV	9	7
Mobile phone (including radio)	41	13

would satisfy their agricultural input information needs. Table 5 presents these results.

Table 5 shows that peers remain the most used channel by farmers to obtain agricultural input information. The factors of (1) calendar planning, (2) planting, (3) water_fertilizer_ pest management (WFPM), and (4) input provision explain 62% of the variance in the seeking behavior (seeking information from peers). This means that farmer's seeking behavior is more informal than formal. The results concur with many studies (Isaya et al., 2018; Kameswari et al., 2011; Macire Kante et al., 2019; Kante et al. 2017a, b, c; Siyao, 2012a) that argue that farmers rely heavily on peers to obtain agricultural (input) information. The second most used channel is the mobile phone which explains about 41% of the variance in the seeking behavior. This means that farmers mostly rely on mobile phone to obtain agricultural input information in addition to seeking information from peers. This represents a formal seeking behavior.

However, in terms of satisfaction, formal seeking behavior through mobile phone satisfies more farmer's needs (R^2 for satisfaction is 13%) than informal seeking behavior (peers). This seeking behavior (through mobile phones) explains 13% of the variance in farmer's satisfaction with the information they obtain pertaining to agricultural input. This study confirms the finding of many studies (Aker et al., 2016; Barakabitze et al., 2015; Kante et al., 2019; Msoffe & Ngulube, 2016) that have found that mobile phones are the channels used by extension services to reach more farmers in developing countries in a timely and appropriate manner. Yet, it should be reported that some of our respondents have commented that the language in which information is conveyed is sometimes inadequate to them, as it is disseminated in French rather than their mother tongue. This language issue has been reported by Nocera and Camara (2015, p. 2) who argued that *…the appropriateness of user interfaces and, at times, the language metaphors used in digital technology were not always assimilated and limited end-users from effectively using the solutions...* The same language issue has been reported by Ssozi-Mugarura et al., (2017). In terms of implication, designers should take into account the language issue in Mali.

The fact that seeking information from peers explains 10% of satisfaction variance does not mean that the model is not consistent. Rather, this signifies that there are other factors that influence the satisfaction of farmer's agricultural input information. These factors could be captured through a qualitative study, which will gather data using interviews and focus group discussion. In turn, these factors should be modeled in conjunction with the factors identified in this study to provide a much more comprehensive model (Fig. 4).

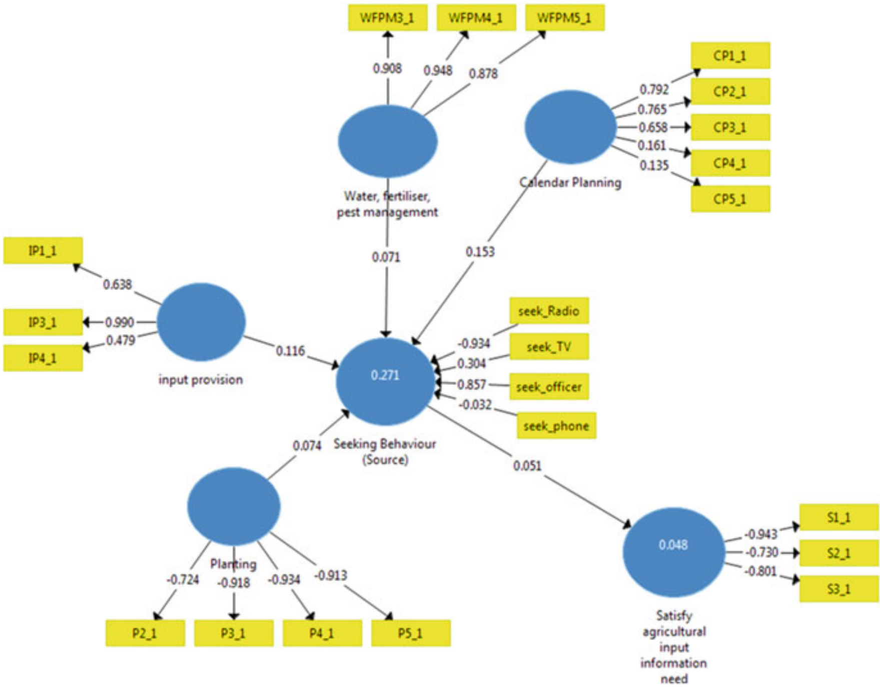

Fig. 4 PLS-SEM results

5 Conclusion

This study investigated the agricultural input information needs and seeking behavior of small-scale farmers in the region of Koulikoro, Mali. The first major finding of this study was that the agricultural (input) information needs of farmers were (1) calendar planning, (2) planting, (3) water, fertilizer, pest management, and (4) input provision. The second major finding was that the farmers seeking agricultural information formally (through their cell phones) are more satisfied than those who do it informally through their peers. The evidence from this study suggests two policy implications. Firstly, Mali's agricultural extension services should encourage the extension officers to implement their interventions in a way that meets farmer's formal information-seeking behavior. Secondly, the extension agencies should encourage the utilization of mobile phones by extension officers as they satisfy farmer's agricultural (input) information needs more than any other information sources.

The generalizability of these findings is limited since the study was conducted in one region in Mali. In addition, the sample was relatively small. The authors suggest a further investigation with more cases to assess our model. This will assist in corroborating the findings from this study.

Appendix

Table 6 Survey questionnaire

Kind of information	Please tick (√) 1 = Always, 2 = Frequently, 3 = Occasionally, 4 = Rarely, and 5 = Never
Land management	LM1. The information that I usually obtained on land management was ultimate, i.e., all the required data to satisfy the actual need for land management.
	LM2. The information I obtained on land management was accurate, i.e., correct for my need for land management.
	LM3. The information I obtained on land management was suited, i.e., the information corresponded to the actual need.
	LM4. The information I obtained on land management was timeliness, i.e., I obtained it when I needed it.
	LM5. The information I obtained on land management was adapted, i.e., in the convenient format and quantity.
Water, fertilizer, and pest management	WFPM1. The information that I usually obtained on water, fertilizer, and pest management was ultimate, i.e., all the required data to satisfy the actual need for water, fertilizer, and pest management.
	WFPM2. The information I obtained on water, fertilizer, and pest management was accurate, i.e., correct for my need for water, fertilizer, and pest management.
	WFPM3. The information I obtained on water, fertilizer, and pest management was suited, i.e., the information was convenient for the current need.
	WFPM4. The information I obtained on water, fertilizer, and pest management was timeous, i.e., I obtained it when I needed it.
	WFPM5. The information I obtained on water, fertilizer, and pest management was adapted, i.e., in the suitable format and quantity.
Crop selection	CS1. The information that I usually obtained on crop selection was ultimate, i.e., all the data required to meet the actual need for crop selection.
	CS2. The information I obtained on crop selection was accurate, i.e., correct for my need for crop selection.
	CS3. The information I obtained on crop selection was suited, i.e., the information was convenient for the actual need.
	CS4. The information I obtained on crop selection was timeous, i.e., I obtained it when I needed it.
	CS5. The information I obtained on crop selection was adapted, i.e., in the suitable format and quantity.
Land selection	LS1. The information that I usually obtained on land selection was ultimate, i.e., all the data required to satisfy the actual need for land selection.
	LS2. The information I obtained on land selection was accurate, i.e., correct for my need for land selection.

(continued)

Table 6 (continued)

Kind of information	Please tick (√) 1 = Always, 2 = Frequently, 3 = Occasionally, 4 = Rarely, and 5 = Never
	LS3. The information I obtained on land selection was suited, i.e., the information was suitable for the current need.
	LS4. The information I obtained on land selection was timeous, i.e., I obtained it when I needed it.
	LS5. The information I obtained on land selection was adapted, i.e., in the suitable format and quantity.
Calendar planning	CP1. The information that I usually obtained on calendar planning was ultimate, i.e., all the data required to satisfy the actual need for calendar planning.
	CP2. The information I obtained on calendar planning was accurate, i.e., correct for my need for calendar planning.
	CP3. The information I obtained on calendar planning was suited, i.e., the information was convenient for the current need.
	CP4. The information I obtained on calendar planning was timeous, i.e., I obtained it when I needed it.
	CP5. The information I obtained on calendar planning was adapted, i.e., in the suitable format and quantity.
Access to credit	AC1. The information that I usually obtained on accessing credit was ultimate, i.e., all the data required to satisfy the actual need for that purpose.
	AC2. The information I obtained on accessing credit was accurate, i.e., correct for my need for accessing credit.
	AC3. The information I obtained on accessing credit was suited, i.e., the information was convenient for the current need.
	AC4. The information I obtained on accessing credit was timeous, i.e., I obtained it when I needed it.
	AC5. The information I obtained on accessing credit was adapted, i.e., in the suitable format and quantity.
Input provision	IP1. The information that I usually obtained on input provision was ultimate, i.e., all the data required to satisfy the actual need for that purpose.
	IP2. The information I obtained on input provision was accurate, i.e., correct for my need for that provision.
	IP3. The information I obtained on input provision was suited, i.e., the information was convenient for the current need.
	IP4. The information I obtained on input provision was timeous, i.e., I obtained it when I needed it.
	IP5. The information I obtained on input provision was adapted, i.e., in the suitable format and quantity.
Planting	P1. The information that I usually obtained on planting on my farm was ultimate, i.e., all the data required to satisfy the actual need for that purpose.
	P2. The information I obtained on planting on my farm was accurate, i.e., correct for my need for that planting.

(continued)

Table 6 (continued)

Kind of information	Please tick (√) 1 = Always, 2 = Frequently, 3 = Occasionally, 4 = Rarely, and 5 = Never
	P3. The information I obtained on planting on my farm was suited, i.e., the information was convenient for the current need.
	P4. The information I obtained on planting on my farm was time-ous, i.e., I obtained it when I needed it.
	P5. The information I obtained on planting on my farm was adapted, i.e., in the suitable format and quantity.

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Part VI
Cross-cutting Themes

Safety and Ergonomics Indexes Applied to Sustainable Supply Chain Evaluation: A Systematic Literature Review

Iván Francisco Rodríguez-Gámez, Aidé Aracely Maldonado-Macías, Juan Luis Hernández-Arellano, Ernesto Alonso Lagarda-Leyva, and Arnulfo Aurelio Naranjo Flores

Abstract Globally, Safety and Ergonomics are aspects that contribute to organization sustainability. Several indicators and metrics (I&M) are used to manage and evaluate such aspects; however, their study is scattered throughout the literature and applied heterogeneously to different levels and parts of the production processes. The objective of this chapter is to conduct a systematic literature review of the most frequently used, I&M, as well as their purpose for Supply Chain (SC) evaluation in its transformation into a sustainable activity and digitalization age. The method followed the PRISMA Guidelines to determine those Safety and Ergonomics I&M most widely used in the SC; they were classified by the economic sector, the quantity, and the supply chain components most evaluated by them. A total of 367 different indicators and metrics were found in 107 selected articles; 95.3% showed use of safety indicators, while 51.4% resorted to ergonomics indicators. Indicators' purposes on SC evaluation such as management lagging and leading were identified as some of the most important. Also seen was a growing interest in this type of research worldwide and, thus, an opportunity for research in the primary sector since manufacturing is the most studied component in the SC. In addition, the I&M were found to achieve only a partial evaluation of the SC and, thus, were deemed ineffective in evaluating all its components.

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Keywords Digitalization age · Safety & Ergonomics (S&E) · Indicators & Metrics (I&M) · Sustainable Supply Chain Management (SSCM) · Systematic Literature Review (SLR)

1 Introduction

Current economies drive companies to take part in the Supply Chain (SC) due to the strong competition to provide products and services in the necessary quantity, quality, and time and at the lowest possible cost. Today, it is more and more common to incorporate the strategy of sustainability into the SC. This approach is defined as the intentional integration of economic, environmental, and social considerations. Under this approach, sustainable supply chains (SSC) are business systems designed to efficiently and effectively manage the material, information, and capital flows associated with obtaining, producing, and distributing products or services in order to meet the stakeholders' requirements and improve the organization's profitability, competitiveness, and resilience over the short- and long-terms (Ahi & Searcy, 2013). Additionally, SSCs view human capital as a key element for effective operations and as the basis for business success (Griffith, 2006) because of its active participation in these complex systems (Clegg, 2000; Kim, 2005; Paillé & Boiral, 2013; Serdarasan, 2013). Furthermore, SSCs act as a social pillar by seeking employees' well-being in their work environment and the prevention of accidents in high-risk systems (De La Garza & Poy, 2009). They also consider the implementation in the workplace of concepts such as occupational health and safety, human-centered work design, empowerment, individual and collective learning, employee participation, and work–life balance. Such concepts aim to preserve or develop human capital (Jasiulewicz-Kaczmarek, 2013). Safety and Ergonomics (S&E) management is included in the social aspect, and, thus, it is on these two fields that the research focuses.

Furthermore, a company that is part of a SC and seeks to implement S&E to achieve sustainability faces several obstacles. One of them relates to its insertion into the digital age, where two relevant aspects are noted: the new risk factors implicit in SC operation and Indicators and Metrics (I&M) accessibility, reliability, and availability. There is currently a wide array of S&E indicators and metrics used to evaluate and control the management of these aspects in organizations. However, such indicators are scattered throughout the literature and are applied at different levels and to different elements of the production processes. Such indicators can play a key role in providing information about organizational performance, motivating people to work on safety, and increasing organizational potential in this area (Reiman & Pietikäinen, 2012).

Conceptually, safety refers to the knowledge about concepts, theories, principles, and methods to broadly understand, evaluate, communicate, and manage the degree of human integrity implied in being safe; that is, in being free from any danger, risk, or injury (Aven, 2013). Ergonomics, on the other hand, is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system; it is the profession that applies theory, principles, data, and methods to design in order to optimise human well-being and overall system performance (IEA, 2000).

Regarding the problem statement addressed by this literature review, Korkulu and Bóna (2019) confirm that the social approach has not been given enough attention either by the Supply Chain Management (SCM) or as part of the sustainability problems addressed by researchers. Therefore, companies and academics have begun working together to help SC migrate toward sustainability (Barbosa-Póvoa et al., 2017; Brandenburg et al., 2014). Additionally, while the literature shows attempts to establish a universally accepted framework to assess social sustainability in SC, this goal remains unattained, and there is misinformation in this regard (Simões et al., 2014). In addition, there is currently a wide array of S&E I&M used to evaluate and control the management of these aspects in organizations. However, such indicators are scattered throughout the literature and are applied at different levels and to different elements of the production processes. Therefore, there is a need to carry out a Systematic Literature Review (SLR) to determine the state of the art regarding S&E I&M for SC sustainability. Other additional objectives are to identify the most widely used S&E I&M and the sectors that apply them, as well as the quantity and components of the SC most evaluated by them. This will help to identify future research areas that may cater for many organizations' growing interest in using such I&M reliably and efficiently.

2 Background

2.1 Definition and Benefits of a Systematic Literature Review

A SLR identifies, selects, and critically appraises research in order to answer a clearly formulated question (Drahota & Dewey, 2016). It is also a complete and transparent search throughout multiple databases and grey literature, which can be replicated and reproduced by other researchers. It should be noted that a SLR must follow a clearly defined protocol, with established inclusion/exclusion criteria for papers and other materials.

Conducting a SLR offers several benefits. First, SLRs clearly and fully describe the available evidence on a given topic. Next, they help identify research gaps in the current understanding of a field. Also, they highlight methodological trends in research studies, to promote future research in different subject areas (Eagly & Wood, 1994). Finally, they are used to provide clear answers to questions on the basis of available evidence (Chalmers & Glasziou, 2009).

2.2 Supply Chain Problems in S&E Management

The International Labour Organization's (ILO) most recent estimates worldwide indicate that 2.78 million workers who work in industries and companies that participate in different components of the Supply Chain die each year from work accidents and occupational diseases. On the other hand, it is estimated that lost workdays represent about 4% of the Gross World Product (GWP), and in some countries, it amounts to 6% or more (Hämäläinen et al., 2017; Takala et al., 2014). These figures show the need to propose reliable and effective indicators in the quest for sustainability.

2.3 Challenges of S&E in the Sustainable Supply Chain

A company that is part of a SC and seeks to implement S&E for sustainability faces several obstacles. Among the most important are the following:

1. Market globalization (Aswell, 2016).
2. Frequent changes in products, manufacturing systems, suppliers, and distribution agents from different companies and nationalities, all of which leads to organizational and administrative shifts and the adoption of new production philosophies (Hasle & Jensen, 2012).
3. Lack of legislation, and the poor implementation of the existing laws to ensure the health and good working conditions (International Labour Organisation, 2016).
4. Lack of international standards that address health and safety aspects in SC (Hasle & Jensen, 2012; International Labour Organisation, 2016).
5. In the digital age, two relevant aspects are noted: the new risk factors implicit in SC operation and I&M, reliability, accessibility, and availability.

3 Methodology

This research used a SLR that followed the PRISMA Declaration (Liberati et al., 2009), as retrieved from its website: http://www.prisma-statement.org/. The document describes the sources of information, the search parameters in the databases, the refinement of the results, the final selection of the identified findings, and an analysis of the results. Figure 1 shows the five stages governing this process.

4 Results

The results obtained during each stage of the SLR are shown below.

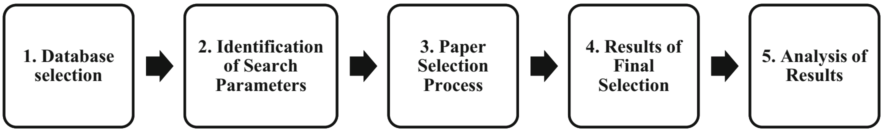


Fig. 1 An overview of the approach used in the research

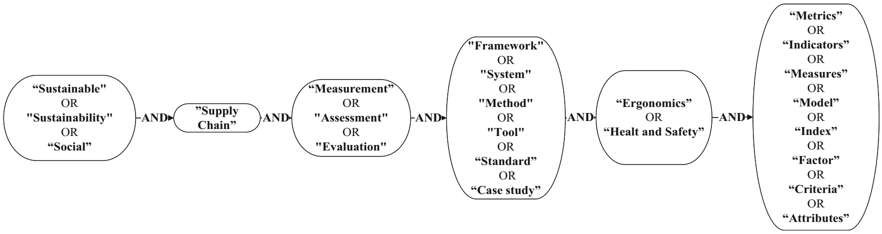


Fig. 2 Relationship between keywords and logical operators

4.1 Database Selection

The search was conducted in the ACM DL, IEEE Xplore, ScienceDirect, ProQuest, SpringerLink, and Emerald Insight databases as these are the most widely used in the engineering, sustainability, supply chain, Safety, and Ergonomics fields, according to the analysis of other systematic literature reviews associated with this topic.

4.2 Identification of Search Parameters

The scope for the SLR for all databases covered journal articles published between 2010 and 2020, and which featured keywords in both their title and content. Logical operators were also considered. Both parameters are shown in Fig. 2.

Inclusion criteria

1. The paper is published in a scientific journal.
2. The paper is available in English.
3. The paper reports on social sustainability indicators or metrics in the supply chain.
4. The paper reports on safety or ergonomics indicators or metrics used in the supply chain.

Exclusion criteria

1. Duplicated papers.
2. Papers in the form of conference posters, abstracts, short papers, and unpublished works.

3. Papers failing to address the sustainability issue in the supply chain.
4. Papers addressing only environmental and economic sustainability.

4.3 Paper Selection Process

A total of 1331 articles were found after the initial search through the six databases. Figure 3 shows the selection process, as well as the results of the screening once the selection and exclusion criteria were established. The results of each stage in the selection process are also featured. It should be noted that the screening process was based on the analysis of all papers in their entirety.

4.4 Results of Final Selection

Figure 3 shows the 107 papers that met the inclusion criteria for final selection. Next, Table 1 shows the total of articles selected, which were in turn classified by year of publication, author, SC component evaluated or analyzed, and type of indicator or metric.

4.5 Analysis of Results

As a result of the aforementioned process, 367 different I&M were identified within the 107 selected articles; 95.3% addressed safety indicators, and 51.4% addressed ergonomics indicators. As can be seen in Fig. 4, the analyzed literature showed a growing interest in the subject studied since publications addressing increased fivefold during the established period. For the last 6 years, the annual number of publications has been above eight, while in previous years, it did not exceed seven

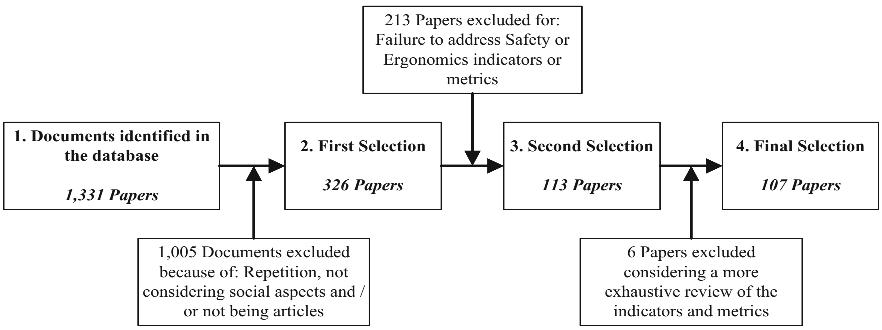


Fig. 3 Paper selection process

Table 1 Characteristics of the selected articles

		SC component evaluated						Type of I&M	
Year	Author (References)	Supplier	Manufacturing	In-Company	Warehousing	Distribution	Costumers	Safety	Ergonomics
2020	Hossan Chowdhury and Quaddus (2021)	X	X	X			X	X	X
	Hoque et al. (2020)	X						X	X
	Gul and Ak (2020)		X			X		X	X
	Taddese et al. (2020)		X					X	X
	Dehdasht et al. (2020)		X					X	X
	Bhanot et al. (2020)							X	X
	Lin et al. (2020)		X					X	X
	Chandra and Kumar (2021)	X	X	X	X	X	X	X	
	Gimenez-Escalante et al. (2020)		X	X			X	X	
	Shrivastava and Unnikrishnan (2020)			X			X	X	
	Tavassoli et al. (2020)	X						X	
	Vegter et al. (2020)							X	X
	Alghababsheh and Gallear (2020)	X	X					X	
	Yıldızbaşı et al. (2020)		X					X	
	Verdecho et al. (2020)	X						X	
	Thies et al. (2020)	X	X			X		X	
2019	Kudelska and Pawłowski (2019)				X				X
	Watterson et al. (2019)		X					X	X
	Yu et al. (2019)	X						X	X
	Li et al. (2019)		X					X	X
	Benotsmane et al. (2019)		X					X	
	Navajas-Romero et al. (2019)							X	X
	Saleeshya and Binu (2019)		X					X	X

(continued)

Table 1 (continued)

Year	Author (References)	SC component evaluated						Type of I&M	
		Supplier	Manufacturing	In-Company	Warehousing	Distribution	Costumers	Safety	Ergonomics
	Korkulu and Bóna (2019)				X				X
	Giannakis et al. (2019)	X	X					X	
	Gong et al. (2019)		X	X			X	X	X
	Moreno-Camacho et al. (2019)							X	
	Tiwari and Khan (2019)	X	X					X	
	Tseng, Wu, Chiu, et al. (2019)	X	X					X	
	Tseng, Wu, Lim, and Wong (2019)		X					X	
	Dey et al. (2019))		X					X	
	Jensen and van der Voordt (2019)			X					X
	Longoni et al. (2019)		X	X				X	X
	Mathiyazhagan et al. (2019)		X	X				X	X
2018	Romero et al. (2018))					X		X	X
	Realyvásquez and Maldonado-Macías (2018)		X						X
	Batista and de Francisco (2018)	X	X					X	X
	Tavassoli and Saen (2019)	X						X	
	Bhakar et al. (2018)		X					X	
	Mohammed et al. (2018)	X						X	
	Osiro et al. (2018)		X					X	X
	Qorri et al. (2018)	X	X	X				X	X
	Rodrigues et al. (2018)			X				X	X
	Tseng, Lim, et al. (2018)	X	X				X	X	
	Tseng, Wu, et al. (2018)		X					X	
	Rentizelas et al. (2018)	X						X	X

	Prasad et al. (2018)		X					X	
	Malesios et al. (2018)		X	X				X	
	León-Bravo et al. (2018)	X	X		X	X		X	X
	Patidar et al. (2018)		X					X	
	How and Lam (2018)	X	X	X	X	X		X	
	Mancini et al. (2018)		X					X	
	Voordt & Van der Voordt and Jensen (2018)		X	X				X	X
2017	Gakidou et al. (2017)							X	
	Lenzo et al. (2017)		X				X	X	X
	Seker and Zavadskas (2017)			X				X	X
	Izadikhah and Farzipoor (2017)	X	X	X	X	X	X	X	X
	Das (2017)	X	X	X	X	X		X	
	Rodríguez-Serrano et al. (2017)							X	X
	Stindt (2017)							X	X
	Kafa et al. (2017)	X						X	
	Kaur and Sharma (2017)		X					X	
	Jafarzadeh et al. (2017)	X						X	
	Rayas and Serrato (2017)		X	X	X	X		X	
	Abbasi (2017)			X				X	X
	A. Reiman et al. (2017)					X		X	X
	Singh and Vinodh (2017)			X				X	X
2016	Sheikhalishahi et al. (2016)			X				X	X
	Bhanot and Rao (2016)			X				X	X
	Jacobs et al. (2016)							X	X
	Gong et al. (2016)							X	
	Parada et al. (2016)	X	X	X	X	X		X	
	Izadikhah and Farzipoor (2016)	X	X					X	

(continued)

Table 1 (continued)

Year	Author (References)	SC component evaluated						Type of I&M	
		Supplier	Manufacturing	In-Company	Warehousing	Distribution	Costumers	Safety	Ergonomics
	Mani et al. (2016)	X	X				X	X	
	Zhou et al. (2016)	X						X	
2015	Longoni and Cagliano (2015)		X					X	X
	Hussain et al. (2015)		X	X				X	
	Maasouman and Demirli (2016)		X					X	X
	Sancha et al. (2015)	X						X	
	Valenzuela and Maturana (2015)	X	X			X		X	
	Khodakarami et al. (2015)	X	X					X	
	Yawar and Seuring (2015)	X						X	X
	Clarke and Boersma (2015)		X					X	X
	Gracia and Quezada (2015)		X	X				X	
	Younis et al. (2015)		X	X				X	X
2014	Jadhav et al. (2014)	X	X	X			X	X	X
	Azadi et al. (2014)	X						X	
	Boukherroub et al. (2014)		X	X	X			X	
	Wolf (2014)		X					X	X
	Shi et al. (2014)	X						X	
2013	Velazquez et al. (2013)		X	X				X	X
	Maldonado-Macías et al. (2013)		X	X				X	X
	Dale et al. (2012)	X	X	X	X	X	X	X	
	Mathiyazhagan and Haq (2013)		X					X	
	Feige et al. (2013)			X					X
2012	Apostolopoulos et al. (2012)					X		X	X
	Govindan et al. (2012)	X						X	

2011	Bi (2011)		X				X	X	X
	Kundu et al. (2011)		X	X				X	X
	Badri et al. (2011)							X	X
	Nikolaou et al. (2011)	X	X		X	X	X	X	
	Baumann-Chardine and Botta-Genoulaz (2011)	X			X	X		X	X
	Erol et al. (2011)	X	X	X	X	X	X	X	
	Laird et al. (2011)			X				X	
2010	Jayal et al. (2010)		X				X	X	X
	Isaksson et al. (2010)							X	
	Closs et al. (2010)	X	X					X	

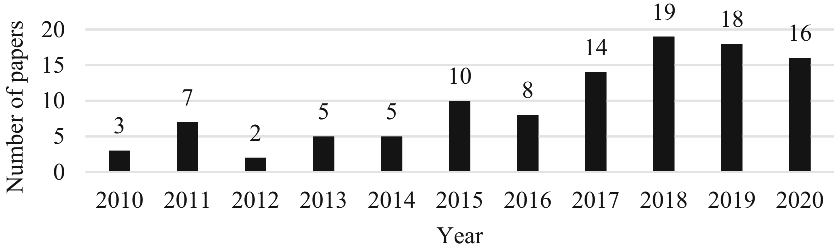


Fig. 4 Year of publication of final selections

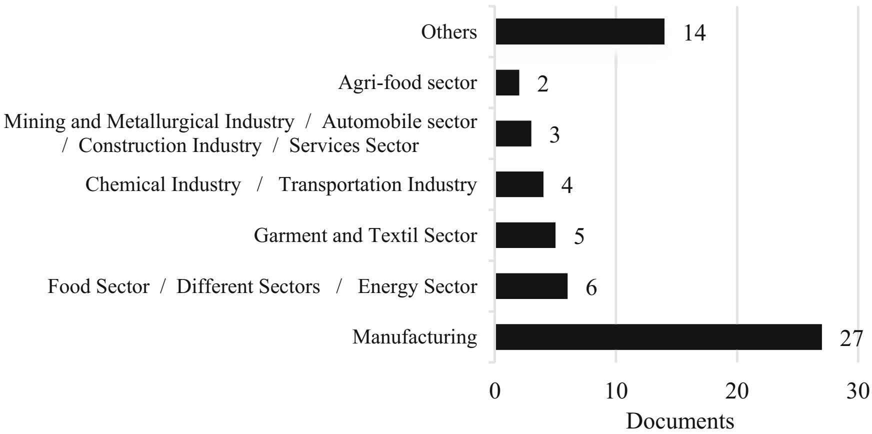


Fig. 5 Types of sectors identified in the research as using I&M in the SC

papers per year. This suggests that the topic is far from being exhausted, and its popularity among researchers is still rising. It is safe to say that further unique studies regarding this field of knowledge will continue to appear soon.

Figure 5 shows the different economic sectors identified as using I&M in the SC. Manufacturing stands out as the most addressed field. Conversely, among the most neglected sectors are healthcare, recycling, storage, waste management, and the biomass industry. Within the primary sector, other areas in need of further research are aquaculture, forestry, the agri-food sector, and mining.

Figure 6 shows the topic-related literature by continent, according to the number of papers found. The Asian continent stands out with 41.12% of the publications and India appearing as its largest representative. In North America, the USA and Mexico lead in publications as does the United Kingdom in Europe. It can be concluded that the attention given to this topic is somehow geographically circumscribed to two continents, which represents an opportunity for the rest.

Another relevant aspect refers to the paper's most studied SC component. Table 2 shows the 107 articles classified by percentages, according to the component studied and ordered by the SC component's logical sequence. As can be seen, an area of

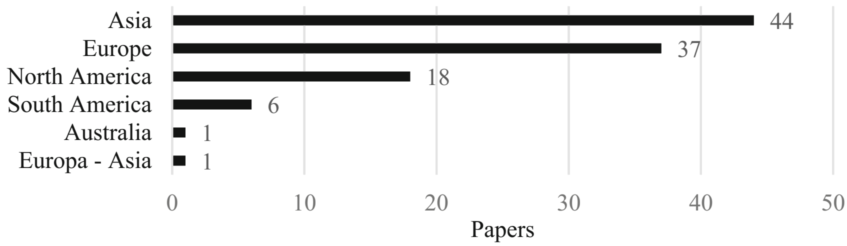


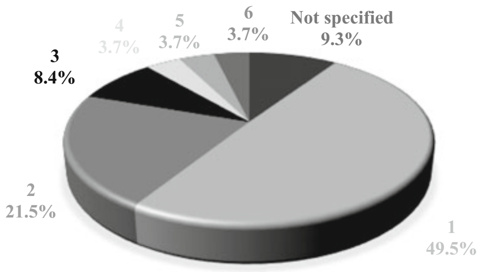
Fig. 6 Number of publications by continent

Table 2 Percentages of evaluation of Supply Chain components

Components evaluated on the SC	Quantity
Supplier	37.38%
Manufacturing	60.75%
In-company	31.78%
Warehousing	13.08%
Distribution	15.89%
Customers	14.02%

Note: It should be noted that in some cases the papers did not assess only one element of the supply chain

Fig. 7 Proportion of the number of SC components evaluated in each paper



opportunity lies on the development of investigations related to S&E management at the following stages: warehouse, distribution, and customers. Such phases involve latent risks for staff and customers, yet they are not deemed as important elements in SC assessment.

Additionally, the articles were analyzed considering the number of SC components evaluated to identify their scope in the total system. Figure 7 shows the percentages of papers found per aspect. It can be noted that only 7.48% of the works propose an analysis and/or a comprehensive evaluation of the system; that is, one where most of the components are evaluated. In such cases, various I&M for S&E are identified in proportions of 93.55% and 6.45%, respectively. However, the use of these Ergonomics I&M appears in only 25% of the evaluations. All these I&M have been used in only a few very specific sectors, such as Energy, and for certain products alone, for example: biodiesel, vaccines, cars, and pasta. Hence, there is a lack of use in other sectors and products. Likewise, there is a lack of a

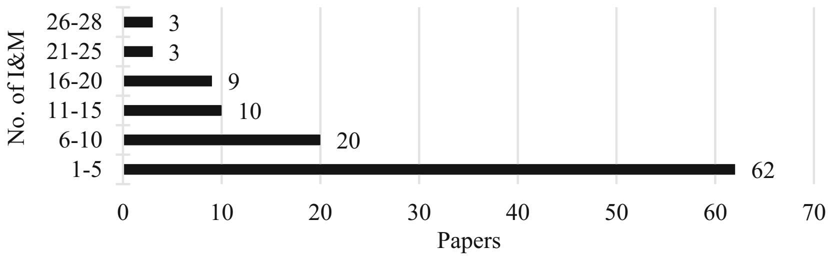


Fig. 8 Frequency of use of Safety and Ergonomics indicators and metrics

comprehensive S&E evaluation by means of a more complete index that can measure and compare the degree of process and organization maturity regarding compliance with these aspects and their regulations. These results show that most of the research found conducts only partial evaluations, thus failing to make a more comprehensive SC analysis, and in the cases where this is done, several S&E aspects applicable throughout the chain are omitted.

Another key aim of this review was to identify S&E I&M. A total of 367 articles were found, 56.68% out of which addressed Safety aspects, while 43.32% pointed to I&M related to Ergonomics. Their frequency of use is shown in Fig. 8. The graph shows a clear polarization as most of them use within 1–5 indicators, while few studies include more complete evaluations involving up to 26–28 different indicators. This shows that, until now, there is no consensus guaranteeing their efficient and reliable use. Hence, it seems necessary to propose global and recognized I&M to achieve greater effectiveness in reaching organizational objectives.

4.6 *Analysis of the Most Widely S&E I&M Used in the SSC*

To complement the previous analysis, Fig. 9 shows the results of the "*word cloud chart*" showing the frequency of I&M. Such frequency is represented by the size of the text: the larger the size, the higher the frequency. In addition, Table 3 orders the indicators from the highest to the lowest frequency of use in papers as shown by the word cloud chart. Position 1 is held by the "Occupational Health and Safety" indicator, which means that it is the most widely used. It is highlighted that of the 367 I&M used in the previous analyses, 67.3% have been used once. Therefore, it seems that the existence of a wide variety of I&M, as well as the lack of consensus in the literature, makes it difficult to select of the most appropriate one for a more complete SC analysis.

Fig. 9 Frequency of S&E I&M use in Supply Chains

5 Discussion

The attention given to this issue is evidence that interest is growing. Ahi and Searcy (2014, 2015) do not only agree with this statement, they also include I&M S&E as measures of social aspects, highlighting their importance in SSCM and in measuring the performance of green supply chain management. These authors consensually and systematically agree on the various difficulties that their use as means of SC evaluation represent. Among such hindrances are the wide range of I&M available to monitor the performance of an organization and the lack of a model, system, or normative framework with international acceptance. Some authors studies were relevant to discuss the relevance of the results of this study. Accordingly, Reiman and Pietikäinen (2012) state that the most widely used safety performance indicators are lagging indicators—which measure outcomes of activities or events that have already happened. Lately, an increasing emphasis has been placed on the role of indicators in informing organizational performance anticipation and development. Indicators for this purpose are called leading indicators. Additionally, da Silva and Amaral (2019) identified more proactive management as a critical success factor for occupational health and safety management; this can be achieved through the monitoring of leading indicators (also referred to as proactive, positive, or predictive indicators). Similarly, an ergonomics program needs to take proactive actions to become sustainable since only the anticipation of undesirable events can lead to prevention (Fernandes et al., 2015).

An analysis of the purposes listed in Table 3 will reveal a balance in the use lagging and leading I&M. However, when zeroing on the assessment of sustainability's three pillars, it can be noted that in most cases, the social approach is monitored by lagging parameters. In S&E management it is essential to have a

Table 3 Top ranking indicators and metrics about Safety and Ergonomics

Items	Type of I&M	Indicator/Metric	Rank	Frequency	Purpose
1	Safety	Occupational Health & Safety	1	34	Lagging
2	Safety	Training/education	2	25	Leading/ lagging
3	Ergonomics	Noise level	3	16	Leading
4	Safety	Safety	4	15	Lagging
5	Safety	Risk chemicals	5	11	Leading
6	Ergonomics	Duration of working hours/maximum working hours/fair working hours			Leading
7	Safety	Working/work conditions	7	10	Leading
8	Ergonomics	Ergonomics workstation			Leading
9	Safety	Injuries	8	8	Lagging
10	Safety	Acute injuries/number of injuries			Lagging
11	Ergonomics	Worker satisfaction			Lagging
12	Ergonomics	Noise			Lagging
13	Safety	Health & safety of customers/ communities	9	7	Lagging
14	Safety	Machine			Leading
15	Ergonomics	Psychosocial stress factors			Lagging
16	Safety	Physical risk	10	6	Leading
17	Safety	Implementing regulations: OHSAS 18001/18002			Leading
18	Ergonomics	Healthy			Lagging
19	Ergonomics	Design or redesign of workstation			Leading
20	Ergonomics	Performance			Leading
21	Ergonomics	Working fast, time pressure, having tight deadlines, not having enough time to do the job, frequent disruptive interruptions			Leading
22	Ergonomics	Education, knowledge, and skills			Leading/ lagging

balance between both types of indicators as this guarantees the efficient monitoring of performance. The use of leading I&M helps to identify the causes of accidents and illnesses, whereas lagging indicators measure the historical performance of compliance with the established S&E goals.

6 Conclusions

This chapter shows an overview of the S&E I&M used in the SSC, through a literature review covering the period from 2010 to 2020. The methodology used followed the PRISMA Guidelines and proved effective in identifying the most widely used I&M as it allowed for the identification of both the economic sectors using them and the quantity and components most evaluated by them. As can be confirmed, the objective of this research was met, which was to establish the state of the art of S&E I&M for SC sustainability. However, both aspects are unbalanced in terms of their use in characterizing SC, with Safety I&M as the most frequently employed. Additionally, regarding the purpose of the indicators, they were classified as lagging and leading in service of a larger goal to SSC.

Regarding the sectors using them, while the manufacturing sector accounts for most of the publications, it lacks a comprehensive evaluation of its SC. It is also recognized that most evaluations are limited to up to five S&E I&M. This creates a debate concerning the reliability of the measures used, which provides a real overview of the operative conditions throughout the SC. Finally, although there are indications involving all components in the chain, they are scarce and applicable only to certain sectors such as the Energy, which shows their limitations in scope. It is evident that there is a lack of a more effective system to evaluate the SC in terms of S&E, a system including standardized I&M that can contribute to evaluating all sectors and components and that may, therefore, facilitate feedback in organizations. This is important for continuous improvement and increasing competitiveness. Furthermore, the wide range and diversity of I&M available makes it difficult for decision-makers, executives, and analysts to select the most appropriate one to use. The low frequency of I&M use and the lack of consensus in the literature cause this difficulty only to increase. A S&E management system should be measured and monitored through both the leading and lagging I&M as they help to achieve an effective management, one that is able to focus on the prevention of occupational accidents and diseases and still meet the goals set by the organization. As can be seen, a theoretical and pragmatic SC evaluation model that provides a comprehensive approach to S&E I&M is needed. In addition, this study's findings point to the need for a comprehensive S&E Management Index for SC sustainability, one that facilitates a comprehensive chain evaluation and provides a unified, relevant, and effective measurement system progressing into the digitalization age.

7 Future Research Direction

These facts suggest new challenges for researchers in this field to promote the development of this topic, enrich the field of knowledge, prevent accidents and occupational diseases, and improve organization performance and sustainability.

The articles analyzed by the SLR were chosen considering parameters related to the SSC. However, it is known that I&M of S&E are not exclusive to this research field. By rejecting those articles which did not consider this aspect, some valuable S&E I&M with potential for implementation in the sustainable approach for SC were also rejected. Thus, an expansion of the exclusion criteria is suggested.

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Ramifications of Ease-of-Use, Access to, and Acceptance of 4IR Technologies in Science Teacher Preparation

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Abstract Regardless of the need to re-direct Science, Technology, Engineering, and Mathematics (STEM*)* education toward rural-based Science teacher preparation, factors such as ease-of-use, access to, and acceptance of fourth industrial revolution (4IR) technologies receive minimal to no integration, compared to other industries (manufacturing, aviation, medicine, astrophysics, and cosmology). The commencement of the 4IR and its associated technologies is however, transforming virtually all facets of business and industries. Informed by the lack of adequate application of STEM in rural-based settings, the current research examines influencers of rural-based Science teachers' preparedness in the context of 4IR technologies. Positioned upon the research aim, the selected methodology was primarily a systematic review. The review assessed both past and present literature via Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Anchored on the stated aim, the research develops a multi-level influence explanation in exploring STEM education which is fit for the rural-based Science teacher preparation. Because of the stated conclusion, the recommendation is that; acceptance, ease-of-use, and access as well as 4IR-related skills are significant influencers of rural-based Science teacher preparation and hence South Africa's teacher training in STEM.

Keywords Fourth Industrial Revolution · Teacher education · STEM education · Adaptive technologies · Twenty-first century skills

1 Introduction

The commencement of the fourth industrial revolution (4IR) and its associated technologies, which are hinged on the groundwork of the first three revolutions, is inescapably transforming virtually all facets and aspects of industries (Abdurrahman, 2018; Junid et al., 2019; Scepanovič, 2019; Kek & Huijser, 2016;

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Ng'ambi et al., 2016; Uerz et al., 2018). For instance, what is pervasive of 4IR and its associated technologies is that its consequence or use cases tend to blur the boundaries between the physical, digital, and biological worlds at an astonishing rate (Sutherland, 2020; Yusuf et al., 2020; Uerz et al., 2018). For example, 4IR technologies such as artificial intelligence (AI), robotics, the Internet of Things (IoT), 3D printing, quantum computing, and other industry-tailored technologies are used to transform biomedical engineering, medical sciences, climate, aviation, autonomous driving cars to mention but a few (Abdurrahman, 2018; Junid et al., 2019; Scepanovič, 2019).

In developed countries and akin to STEM research, Junid et al. (2019); Ng'ambi et al. (2016) and Scepanovič (2019) argue that many studies are being conducted into 4IR technology integration with aforesaid disciplines. However, in developing countries, limited effort is directed at the preparedness of Science teachers, particularly in South Africa as illustrated in the cases in point (as one reads on). For instance, this limited effort is mostly further impeded by factors such as ease-of-use, access to, and acceptance of 4IR technologies such as adaptive technology (e-learning, m-learning, GeoGebra, sketch pad, MATLAB, geographic information systems (GIS), sensor networks, virtual and augmented reality (VR and AR), and blockchain technology (Abdurrahman, 2018; Adesina, 2019; Junid et al., 2019; Scepanovič, 2019; Uerz et al., 2018). While research currently cautions and raises alarm regarding the aforementioned factors, we still do not fully comprehend the ramifications of such factors, particularly preparation of rural-based Science teachers in developing countries, and specifically in South Africa (Adesina, 2019; Junid et al., 2019; Ng'ambi et al., 2016). It is also evidenced that effects of 4IR are more felt in manufacturing, aviation, medicine, astrophysics, and cosmology as opposed to STEM education. The evidence is rooted in recent research by Silman et al. (2017) regarding the use of assistive technology for administrative processes for the visually impaired people. Xu et al. (2018) also highlighted the growing opportunities associated with 4IR in the automotive industries. Other key evidence includes but not exclusively the changes associated with future of employment, skills, and workforce strategy (Schwab, 2016) and Technology-enhanced processes in South Africa (Ng'ambi et al., 2016). What that means is that due to the rapid changes associated with 4IR, (Ng'ambi et al., 2016); Silman et al. (2017) and Xu et al. (2018) conclude that STEM education lags behind in terms of ease-of-use and consequently the access to and acceptance within the education sectors in developing countries (such as South Africa) (Junid et al., 2019; Scepanovič, 2019; Sefotho, 2015; Uerz et al., 2018). Consequently, the key research question is, how do ease-of-use, access to, and acceptance of 4IR technologies influence Science teacher preparation? Based on the synopsis this far, the key aim is to examine the ease-of-use, access to, and acceptance of 4IR technologies in Science teacher preparation. To achieve the main aim, the following objects are proposed: The first is to analyze the preparedness of rural-based Science teachers' and acceptance of 4IR technologies. The second is to examine rural-based Science teachers' ease-of-use of 4IR technologies and lastly, to evaluate the rural-based Science teachers' access to 4IR technologies.

2 Methodology of Study

Based on the aim of the study, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method was employed (Kitchenham & Brereton, 2013; Enticott et al., 2017). The principle underpinning PRISMA method is guided by a systematic review of both past and present literature. To ensure the research meets methodologically acceptable standards of PRISMA, Enticott et al. (2017) suggest that the standard operating procedure should be observed for conducting as well as reporting a systematic review. First, crucial constructs including acceptance, 4IR context, 4IR technologies, preparation of rural-based Science teachers, STEM education were considered. The ISI, IBSS, ScieLO SA, and SCOPUS electronic search constituted the main databases—which was the second factor to be considered. This was because, it allows for both South African (local) literature reviews as much as it does for international sources. Third, the eligibility criteria based on the search terms were informed by constructs resulting from the objectives.

Thus, the research starts by re-evaluating the need to situate teacher and higher education in the context of 4IR (Newman & Gough, 2020). To accurately fulfill such re-examination as suggested by Schwab (2016); Xu et al. (2018); and Yusuf et al. (2020), it was imperative to position teacher and higher education in a well-defined notion of what we mean by the acceptance of 4IR. The next task, as guided by Abdurrahman (2018); Scepanovič (2019); Junid et al. (2019), was to examine the ease-of-use of 4IR. The author also drew from the work of Kek and Huijser (2016); Ng'ambi et al. (2016); together with Uerz et al. (2018) in an effort to examine what it means to transform HEIs through access to 4IR technology. Based on the objectives, the author simultaneously discuss' the implications and developed a conceptual understanding for the preparation of rural-based Science teachers.

3 Related Work

Based on the research aim, it was crucial to examine the preparedness of education system for 4IR. It is important because, it helps in aligning the education systems with the demands of 4IR. Thus, among the review of work, the current section examines: (1) preparedness of rural-based Science teachers' acceptance of 4IR technologies (2) ease-of-use of 4IR technology among rural-based Science teachers, and lastly (3) rural-based Science teachers' access to 4IR technologies.

Notwithstanding the notion that access and acceptance jointly improve the ease-of-use of 4IR technologies, simultaneously, they create a need for specialized skills (Junid et al., 2019; Scepanovič, 2019). The view of Junid et al. (2019) and Scepanovič (2019) is particularly true in Science teacher preparation. Consequently, the pedagogical approaches to Science teaching, access to and acceptance of 4IR technologies need to be investigated. The implication is that the current skills set in education sector are in their infantry stages compared to medicine or aviation regarding the use of 4IR (Subkhan & Widhanarto, 2017; Uerz et al., 2018). For instance, ease-of-use, access to, and acceptance of sensor networks, virtual and augmented reality (VR and AR), and blockchain technology are less evident in Science teacher preparation and accordingly, the pedagogical approaches to Science teaching, and this is particularly the case in rural settings in South Africa (Zawacki-Richter et al., 2020).

Arguably too, factors such as critical thinking, innovation, problem-solving, and life-long learning tend to constitute the unique skills that need to be tailored toward 4IR technologies. While not exhaustive evidence, the debate on such factors could be seen in the need to accelerate workforce reskilling for the 4IR (Egetenmeyer et al., 2017). Similarly, recent history on such factors has gained prominence in not only the implementation of e-learning in developing countries (Al-Adwan & Smedley, 2012), also teaching styles inspired by academic engagement that is built upon online environment (Chae & Shin, 2015; Egetenmeyer et al., 2017; Al-Adwan & Smedley, 2012). Chae & Shin's (2015) viewpoint is hinged upon the fact that while there is the need for skills, in contrast, the factors are misaligned in the preparation of rural-based Science teachers. Consequently, the need for better pedagogical approaches to Science teaching under the current education system in South Africa (De Freitas & Spangenberg, 2019; Joynes et al., 2019; Sefotho, 2015).

It is essential to evaluate the preparedness of our education system for 4IR so that necessary adjustments can be made to align education with the demands of 4IR. Drawn from the aforementioned cases and misalignment of skills, there is, consequently, a need, to essentially re-evaluate ease-of-use, access to, and acceptance of 4IR technologies with the view of aligning the special skills with the current demands of the 4IR. As asserted by De Freitas & Spangenberg (2019); Joynes et al. (2019); Yusuf et al. (2020), the motive for such re-evaluation is that through STEM education, for instance, 4IR skills can be imparted to the preparation of rural-based Science teachers, and that STEM education provides a platform for further research to fine-tune 4IR technology for the improvement of human life. Another motive is that significantly improved preparation of rural-based Science teachers can be achieved via STEM education, which responds to; ease-of-use, access to, and acceptance of 4IR technologies (Sutherland, 2020; Yusuf et al., 2020). While there may be multiple implications, what is meant is the need to educate while accounting for 4IR skills and competencies and thus future-ready learners (Tan et al., 2017). Equally important as alluded by Tondeur et al. (2017) is understanding the relationship between teachers' pedagogical beliefs and technology use in education, just as much as comprehending contextual principles when introducing ICTs into remote, low-income educational environments (Trucano, 2013). The collective gaps identified through the work of Trucano (2013); Tan et al. (2017); Tondeur et al. (2017); Sutherland (2020) and Yusuf et al. (2020) necessitate the need for the current research.

Rural-Based Science Teachers' Preparation, Acceptance of 4IR Technologies and Sustainability via STEM Education

Bezovski and Poorani (2016) find that the acceptance of 4IR technologies started after the popularization of the Internet and the Web. Bezovski and Poorani (2016) further submit that 4IR and its associated technologies have many benefits, on the one hand, for the preparation of Science teachers, and eventually, for the learners. The use of 4IR technologies is also already spreading from the formal education field to the informal one (Ng'ambi et al., 2016). In this process, teacher involvement and therefore preparation of rural-based Science teachers will occupy a central role. To ensure that one appreciates what is involved in the preparation of rural-based Science teachers, it is essential to assess and understand the acceptance of these technologies. This includes the different forms of 4IR (GIS, programming languages, sensor networks, VR and AR, IoT, blockchain technology, and AI).

However, not enough evidence exists to understand the current technology acceptance level, or the extent to which users come to accept and use technology in the preparation of Science teachers (Miguelane et al., 2017). In response to such lack of understanding, the technology acceptance model (TAM) or theory presents a suitable tool that has been frequently used by researchers when studying the adoption process of information systems (IS) in most non-educational contexts (Miguelane et al., 2017). The advantage of using the TAM model is that it can be expanded and designed for the evaluation of the acceptance of the 4IR technologies in the preparation of Science teachers (Junid et al., 2019; Kek & Huijser, 2016; Lapek, 2018). For instance, Miguelane et al. (2017) state that TAM's perceived usefulness is strongly associated with the behavioral intention to use technology. The perceived ease-of-use is related to the perceived usefulness, and self-efficacy is associated with perceived ease-of-use. Therefore, using the previously stated constructs, which constitute the TAM model, and understanding the constructs that describe the preparation of Science teachers, teacher training could adopt the TAM model as a relevant theoretical framework. This is particularly important for the preparation of rural-based Science teachers' acceptance of 4IR and its associated technologies via STEM education.

Despite the benefits, acceptance of 4IR technologies has been recognized as a challenge for rural communities' sustainability and hence, the preparation of rural-based Science teachers. For example, research has shown that teachers in rural communities lag behind their peers in urban areas regarding the acceptance of such preparation, and hence, learners perform poorly in STEM education in rural schools (Hlatswayo & Ramnarain, 2018; Trucano, 2013). Paradoxically, most developing countries' education sector policies advocate for the acceptance and use of technology in teaching and learning (T & L) in schools in order to sustain and to meet the demands of 4IR in the twenty-first century. However, with reference drawn from the fact that most preparation of Science teachers in rural communities does not use 4IR and its associated technologies in teaching, it is not surprising that learners perform below expectation (Chae & Shin, 2015; Letseka, 2015). According to Marbán & Mulenga (2019), the acceptance and consequently the use of 4IR and its associated technologies could enhance the teaching performance of not only

Science, but STEM education in general. Consequently, the current paper argues that understanding the preparation of Science teachers in terms of their acceptance of 4IR and its associated technologies will assist in addressing the challenges and particularly rural-based Science teaching and sustainability.

Paradox 1—Even though the technologies include but are not limited to blended learning, micro-learning, and personalized learning technologies, however there is insufficient evidence of acceptance of the various pedagogical methodologies employing 4IR, and how such technologies are embedded in the preparation of rural-based Science teachers (Bezovski & Poorani, 2016). Currently, there is also the need as suggested by Junid et al. (2019) to explore broad issues associated with the service provision of 4IR technology in rural school settings.

Ramification 1—Dalgarno (2008) reported that the core competencies needed in the twenty-first century are digital literacy in order to bridge the wide gap between urban and rural settings. This implies that digital technology via 4IR and the associated technology trends are needed in nearly all facets of life. Hence, the use of technology has become a basic requirement in education. In turn, this necessitates that teachers have to develop the relevant 4IR skills, and it is essential that the preparation of Science teachers improves the engagement in learning, and to use and access quality education. Since 4IR and its associated technologies provide access to up-to-date information, it is useful for the preparation of Science teachers in rural/isolated areas to be situated within the context of 4IR.

Influence of Ease-Of-Use on the Preparation of Rural-based Science Teachers in the Context of 4IR

The debate has endured for some time that the preparation of Science teachers needs the necessary consideration (Junid et al., 2019; Ding et al., 2019; Ertmera et al., 2012; Georgina & Olson, 2008). For instance, Junid et al. (2019) examined Science teachers' understanding in a 4IR context together with their readiness to handle transformation. Ding et al. (2019) analyzed teachers' pedagogical beliefs as well as practices in terms of technology. Teachers' beliefs and how teachers integrate technology into practice have also been examined by Ertmera et al. (2012) and Georgina & Olson (2008).

However, what is drawn collectively from these studies is that while a significant number of studies address the preparation of Science teachers in urban contexts, limited attention is extended to the preparation of Science teachers and thus their use of 4IR technologies in rural/isolated areas (Phang et al., 2017; Silman et al., 2017). Most importantly, a significant problem has been the lack of information regarding the ease-of-use of 4IR and its associated technologies via STEM education (Lim & Chai, 2008; Silman et al., 2017). For instance, Silman et al. (2017), who examined the use of assistive technology, suggest that there is the need to improve the ease-of-use of assistive technology, particularly in T & L as well as in the administrative processes.

Paradox 2—Regardless of the ramifications, the paradox of the preparation of Science teachers regarding the ease-of-use of 4IR and its associated technologies via STEM education is how to provide a measurable increase in rural/isolated areas (Tan et al., 2017; Telukdarie & Munsamy, 2019; Tondeur et al., 2017). Consequently, there is a need to improve rural-based Science teachers' preparation skills to a satisfactory extent by taking 4IR technologies into account (Telukdarie & Munsamy, 2019; Uleanya & Ke, 2019). Another paradox is how to enable the preparation of rural-based Science teachers to be able to access the general curriculum through the use of assistive teaching technologies when trying to teach Science through the use of 4IR technologies (platforms such as Google Classroom, Zoom, and e-schools) (Wan et al., 2016). Currently, providing rural-based Science teachers with 4IR multi-skills for the preparation of alternative teaching that will help them teach anytime anywhere is not well understood (Xing & Marwala, 2017; Xu et al., 2018). Additionally, the paradox is that little attention is paid to assisting teaching and information sharing between rural teachers and urban teachers if they are away from their regular classrooms.

Ramification 2—The argument for the preparation of Science teachers to focus on the ease-of-use of 4IR technologies via STEM education is anchored on Silman et al.'s (2017) notion that the ease-of-use of 4IR and its associated technologies via STEM education is expected to be instrumental in an increase in the number of Science teachers who use e-learning technologies in rural/isolated areas (Penprase, 2018; Petko, 2012; Prestridge, 2017; Silman et al., 2017). For instance, some of the 4IR technologies such as artificial intelligence (AI), robotics, Internet of Things (IoT), and 3D printing can be used in the pedagogical stages of training student-teachers as suggested by Silman et al. (2017). Other adaptive technologies in 4IR can also be of great assistance in rural/isolated areas (Schwab, 2016; Silman et al., 2017). These include but are not exclusively classified as e-learning and mobile-learning (m-learning) technologies such as MATLAB, GIS, and sensor networks.

Preparation of Rural-Based Science Teachers' Access to 4IR Technologies
Access means suitable and effortless flexibility built in the right to use 4IR technologies, when issues of time and place (urban, peri-urban, or rural) are taken into consideration (Al-Adwan & Smedley, 2012). This implies that every student-teacher should have the "luxury" of being able to choose the place and time that suits their learning needs. To clarify the point, Al-Adwan & Smedley (2012) argue that the adoption of 4IR and its associated technologies provide the preparation of Science teachers as well as the pedagogical approaches to Science teaching in a 4IR classroom with the much-needed flexibility of time and place of delivery or receipt of learning information. The challenge is that while the majority of access to 4IR and its associated technologies is channeled into urban settings, the same does not hold true for rural settings (Al-Adwan & Smedley, 2012). Cognizance of this challenge, literature has sought to explain that 4IR technologies could make a significant impact in the preparation of Science teachers as well as on the pedagogical approaches to Science teaching (Mwaniki et al., 2020).

Another reason why further attention needs to be directed toward the preparation of rural-based Science teachers' access to 4IR technologies via STEM education is because of the wide digital divide or inequality between urban and rural settings. Access to 4IR and its associated technologies via STEM education during the preparation of rural-based Science teachers could bridge the wide digital divide or inequality between urban and rural settings, and consequently, make it easier for student-teachers who are currently experiencing limitations to access learning activities (Al-Adwan & Smedley, 2012). Accordingly, the expectation is that 4IR and its associated technologies could assist in making student-teachers acquire self-paced success in education because of significant individualized support being available at all times and places (Hayashi et al., 2004; Wentzel, 1997). Thus, while 4IR and its associated technologies are considered a solution to T & L challenges, the preparation of rural-based Science teachers still remains a challenge, consequently leading to an inadequate/inappropriate selection of skills for 4IR and its associated technologies. Hence, another motive is to focus on 4IR skills (Mwaniki et al., 2020),

Ramification 3—The motive of access to 4IR and its associated technologies via STEM education is built on the premise that the preparation of Science teachers will be able to access the general curriculum through the use of assistive technologies, for instance, e-schools (Hussin, 2018). This means that research also has to aim at equipping teachers with the necessary multi-tasking skills for alternative teaching, where teachers will be able to use 4IR technologies, among others. The preparation of rural-based Science teachers in relation to access to 4IR and its associated technologies is predicated on the fact that teachers in rural schools will be able to share ideas on teaching STEM (Science) with teachers in urban schools. Collective ramification could be that teachers in rural schools will be able to manage e-schools accordingly.

Anchored on ramification 3, 4IR and its associated technologies are becoming a critical focus not only for the preparation of Science teachers, but also for the context of accessibility. It can be deduced from the assessment this far that 4IR and its associated technologies significantly add to the importance of digital literacy and digital freedom for all preparation of Science teachers. A case in point is that while T & L have been forced to shut down worldwide due to the Covid-19 pandemic, significantly, rural educators and learners in developing countries such as South Africa, have been adversely affected, compared to many of their counterparts in urban settings. Arguably, T & L in developed countries or urban areas has not been adversely affected as much as in rural settings. For instance, many urban educators and learners are engaged in learning through the use of platforms such as Google Classrooms, Hangouts, Zoom, and other m-learning resources. This creates a gap in T & L between rural schools and urban schools and necessitates that access to 4IR and its associated technologies has to be addressed via issues of *time and place (urban, peri-urban, or rural)* or accessibility.

4 Discussion of Related Work

Science, though unpopular among some learners, is among the required subjects in any developed or developing country's education curriculum such as South Africa (Al-Adwan & Smedley, 2012; Bezovski & Poorani, 2016; Chae & Shin, 2015; De

Freitas & Spangenberg, 2019; Makgato, 2019; Ng'ambi et al., 2016). The reason for this is that company owners in the manufacturing, building, health, economic, and trade sectors require employees who are equipped with scientific skills. With emerging innovations in the 4IR and its associated technologies, the education sector, and particularly STEM, cannot afford to be left behind. For instance, there are new digital and innovative techniques that have adapted 4IR problem-solving capabilities and fostered competitive and differentiated advantages.

However, among the limited use of 4IR technologies in STEM, one finds, for instance, computer application systems (CAS) in the form of GeoGebra, an e-learning platform that enhances figures, and shapes cognition in Science and Mathematics. One anecdotal evidence is that GeoGebra is a dynamic computational software to enhance Science and Mathematics instruction (De Freitas & Spangenberg, 2019; Makgato, 2019; Ng'ambi et al., 2016). The technology merges the use of dynamic Geometry software (DGS) with some features of CAS and hence, permits combining concepts in Algebra, Geometry, and Calculus, which are somewhat applicable to Science teaching and hence STEM education.

Regardless of the anecdotal evidence as exemplified by DGS, some enquiries on the integration of 4IR technologies, particularly in urban schools, have so far been conducted, leaving out rural-based schools due to their geographical remoteness and inaccessibility (Egetenmeyer et al., 2017). It is this rural–urban divide that has disadvantaged rural-based learners and kept them lagging behind in terms of the incorporation of 4IR technologies. This also applies to the preparation of rural-based Science teacher instructions. Consequently, there is evidence of rural–urban learners' achievement discrepancies within STEM education in South Africa and Africa at large (Lapek, 2018; Letseka, 2015; Makgato, 2019; Mwaniki et al., 2020; Sickel, 2019). That is, urban-based learners tend to outperform their rural-based counterparts in Mathematics education (Letseka, 2015; Makgato, 2019; Mwaniki et al., 2020). It is this rural–urban digital divide that the current research aim is built upon and examines via the ease-of-use, access to, and acceptance of 4IR and its associated technologies by STEM preparation of rural-based teachers in South Africa. Chang et al., (2019) agree that 4IR technologies are the ideal tools (platforms) to be used to expand the conceptualization of subject content. In light of the aforementioned, the inclusion of 4IR technologies in the preparation of Science teachers is of paramount importance (Bruner, 2016; Maxima, 2019).

Despite the significance, Makgato (2019) confirms that the ease-of-use, access to, and acceptance of 4IR technologies in the preparation of Science teachers rarely occur in rural settings in Africa. Moreover, there appears to be little evidence of 4IR and its associated technologies in any preparation of Science teachers in South Africa (Makgato, 2019; Ng'ambi et al., 2016). Hence, there is need to examine how STEM education can be improved through the utilization of 4IR and its associated technologies. The hypothetical stance as a consequence of the examination is that; (1) acceptance, (2) ease-of-use, (3) access, and (4) 4IR-related skills all influence the preparation of Science teachers, which accordingly affect rural-based STEM teachers in South Africa.

5 Conclusion

This paper opened with the statement that commencement of the 4IR and its technologies has virtually transformed all aspects of industries. Accordingly, a reflective and re-engineered model to the preparation of Science teachers and particularly rural-based STEM teachers in South Africa needs to be re-considered. Provided that we do not disaggregate the analysis thereof; the position of the current paper is thus asserted on these four dimensions (ease-of-use, access, acceptance, and 4IR skills). Drawn from the hypothetical conclusion and practical implication, new research will be required to examine further the extent to which South Africa's teacher training regarding STEM is affected by (1) the acceptance, ease-of-use, and access as well as (2) of the 4IR related skills, which must be central to the preparation of rural-based Science teachers. The paper argues that it is through such constructs in the preparation of rural-based Science teachers that South Africa's teacher training in STEM can realize new skills. Thus, a well-defined model in a context or rural-centric focus should be inculcated in the demands of 4IR and its associated technologies.

Contribution Having considered the aim as well as ramifications of the study, using 4IR technologies in the preparation of Science teachers, the first general contribution and need is to address; (1) acceptance, (2) ease-of-use, and (3) access. Unfortunately, the paradox is that rural schools are disadvantaged for reasons due to acceptance, ease-of-use, and access. The second contribution is built upon the ramifications and paradoxes—this is based on the fact that new skills will be required in science teacher preparation to work with these technologies even if acceptance, ease-of-use, and access to the use of 4IR technologies are addressed.

General Implication As a consequence of the contribution, the hypothetical stance and thus the practical implication reached is that; (1) acceptance, ease-of-use, and access as well as (2) 4IR related skills are significant influencers regarding the preparation of rural-based Science teachers and in effect South Africa's teacher training in STEM.

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Analyzing Environmental Risks for Sustainable Supply Chains: A Geospatial Analytics Approach

Ahmad Pajam Hassan, Jorge Marx Gómez, and Frank Passing

Abstract Environmental issues, such as climate change, depletion of natural resources, hazardous emissions, waste, and extreme weather are increasing global concerns in society and business. According to World Economic Forum's Global Risk Survey, environmental issues have the highest likelihood to impact business. Therefore, companies need to address environmental protection and sustainable supply chains (Sustainable Development Goal 9). Especially in times of globalization supply chains are complex and companies are facing challenges integrating environmental risk data into their business processes, because environmental risk events are not linked to their supply chains. In this article, we present a novel approach by applying geospatial analytics to public environmental risk warnings to enhance the process of supply chain risk management in business.

Keywords CSR · Sustainabile supply chains · BDA · Geospatial analysis · Risk analytics · Risk management

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1 Introduction

1.1 Motivation

Climate change is increasingly recognized as risk for business owners (World Economic Forum, 2021). The growing frequency and/or severity of extreme weather led to increased insurance cost, more damages to property and resources, disruption of power and water supply as well as supply chain shortages due to climate change events in the supplier country. Beside weather warnings (e.g., hurricanes or floods), geological alerts like earthquakes or tsunamis, radiological catastrophes like the contamination caused by nuclear power plants, to name only a few, are different types of risk categories and risk events affecting global supply chains (Brinkmann, 2020). According to these risk types, several public warning systems (PWS) have been applied to inform in case of emergency. The risk event databases and their notifications are often publicly available and can be accessed via webservices, email, SMS, and fax (Kox et al., 2018).

Thus, integrating publicly available data into supply chain management (SCM) processes creates a momentum for sustainable supply chains (Bag et al., 2020). Several studies exploring the impact of data analytics in SCM have identified knowledge gaps (Waller & Fawcett, 2013; Tiwari et al., 2018; Wang et al., 2016; Gunasekaran et al., 2017; Bag et al., 2020) as well as the empirical validation of the new data-driven concepts (Ho et al., 2015). However, the combination of data analytics and risk management play an important role to gain new insights for the risk appetite of companies, organizations, and stakeholder (Waller & Fawcett, 2013; Bendel et al., 2021).

Since the integration of publicly available risk event notifications into supply chain risk management is not fully explored in research, we propose a novel approach by applying geospatial analytics to public environmental warnings to enhance the process of supply chain risk management (SCRM), as part of the SCM.

1.2 Problem Statement and Research Questions

Public warning systems got recently high attention in research due to the COVID-19 pandemic (Fearnley & Dixon, 2020; Lee et al., 2021). PWS should alert and inform citizens that are threatened by risk events, enabling them to prepare and act in a timely manner (Niebla et al., 2016). “These systems consist of private or commercial infrastructure designed to enable instantaneous or continuous broadcasting of information to the public. The most primitive form of this type of systems includes a network of sirens that sound imminent threats and communicate the ongoing state of an event” (Kolios et al., 2016). A public warning system can be characterized by four

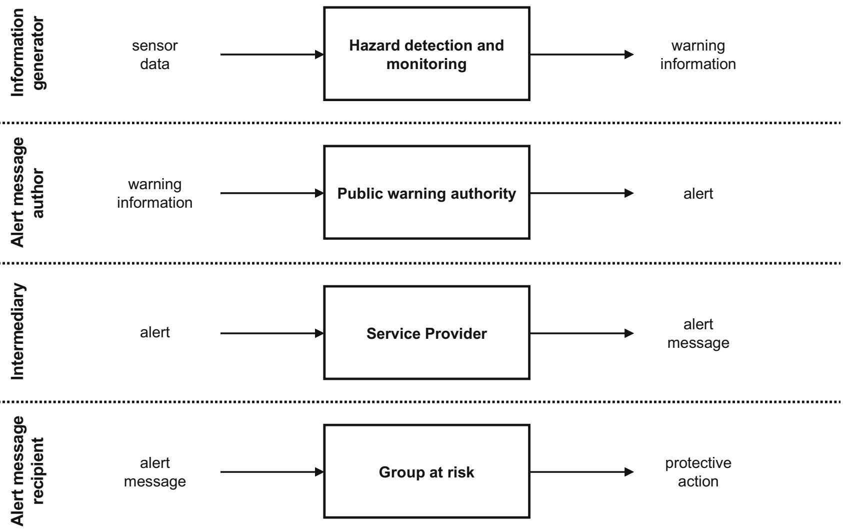

Fig. 1 Involved actors of a public warning system (with reference to Niebla et al., 2016)

actors in the information flow from information generation to alerted recipients. The two main actors of a warning system are the information generator and the alert message author. Together they detect emergencies and generate a dedicated notification. An intermediary often operates the communication technology for alert distribution. The fourth actor is the recipient, who could be a local, regional, national, or other specified community (Niebla et al., 2016). Figure 1 illustrates the information flow between involved actors in a public warning system.

Although external data sources from public warning systems with a focus on environmental risks exist, companies cannot directly integrate that data into their supply chain risk management processes. The main reason lies in the challenge that public warnings are not linked to companies, or in particular to supplier data. However, overcoming the entity linkage challenge can reduce current information deficits in the process of risk identification, assessment, mitigation, and monitoring. Without an automated linkage of external risk information with internal supply chain information, process costs for handling risks are high and the reaction time of the risk mitigation step is further reduced (Moder, 2008).

To force the linkage challenge, knowledge about data analytics concepts as well as prototypes to systematically identify the relation between external data and supply chain entities (especially supplier, focal Original Equipment Manufacturer (OEM), Customer) is essential (Waller & Fawcett, 2013).

This is where geospatial analytics approaches offer advantages to identify potential environmental risks within a supply chain.

1.3 Goals, Research Questions, and Delimitations

Against the backdrop of Information System Research, the goal of our work is to generate insights on the potential of geospatial analytics for SCRM and to contribute positively to the SDGs. In this context, our research contributes toward (i) a conceptual model for using geospatial analytics for environmental supply risk identification, and (ii) an implementation to evaluate the designed concept and provide further insights for integrating external data into SCRM. To achieve these objectives, the following research questions lead our investigation and will be answered:

- RQ1: What are the essential requirements for linking public warnings to supply chain information?
- RQ2: How can a conceptual model of an artifact be designed, to identify environmental supply risk based on public warning data?
- RQ3: What might an instance of the conceptual model look like?

1.4 Research Methodology

Design science research is defined as "Research that invents a new purposeful artefact to address a generalized type of problem and evaluates its utility for solving problems of that type" (Venable & Baskerville, 2012, p. 142).

Artifacts can be separated into system designs, methods, notations, algorithms, guidelines, requirements, patterns, or metrics (Offermann et al., 2010). The designed artifact has the aim to solve and improve real world problems (Myers & Venable, 2014). In our research three different artifacts will be developed:

- Requirements for a geospatial environmental risk identification method
- A conceptual model of the risk identification workflow
- An implementation of the conceptual model as proof of concept

These three artifacts address issues in the field of SCRM and can improve sustainable supply chains. Our research approach is based on design science research framework according to Johannesson and Perjons (2014), see Fig. 2. In our first step, we define the fundamental problem of environmental supply chain risks. Afterward we describe the current situation, why SCRM can be improved by the means of data analytics. To design a model for a geospatial environmental supply chain risk identification method, a literature review will be carried out to identify relevant requirements. In a next step, we develop a conceptual framework for integrating public warning systems into supply chain risk management processes. Since the data from multiple sources, e.g., internal supply chain data and external sources like from USGS, is quite heterogenous, we designed an enhanced supply chain risk data schema based on the international standard Common Alerting Protocol (CAP), which is commonly used for public warning systems worldwide. Based on these findings from the literature review and the analysis of the data, we derive

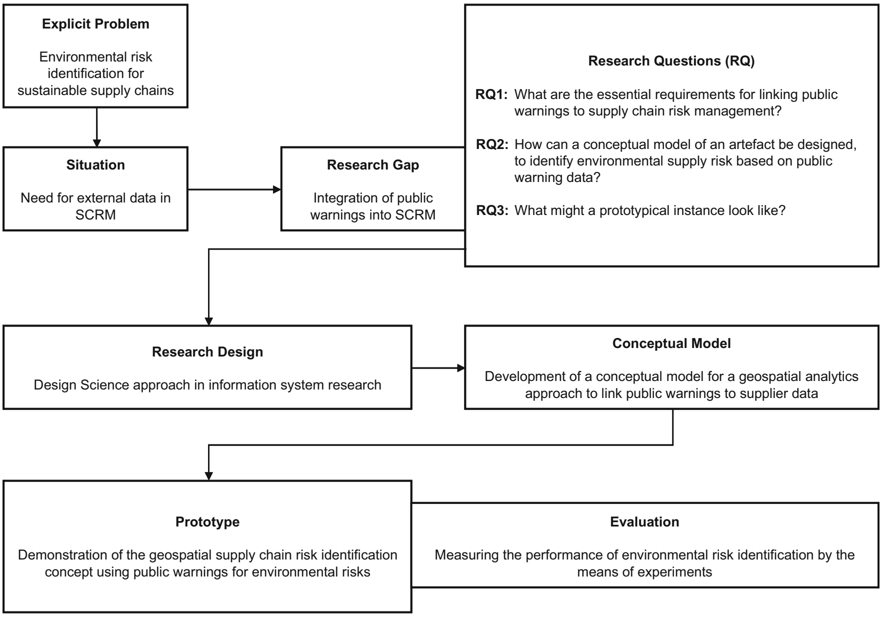

Fig. 2 Research design to develop a concept and an implementation of a geospatial supply risk identification method

requirements for a prototype. In a final step, we develop a technical implementation and test the geospatial supply risk identification model by three case studies, focusing on the geospatial analysis of (i) risk events, (ii) industry-specific risk profiles, and (iii) location-specific risk profiles.

2 Literature Analysis

In recent years data analytic approaches in supply chain management became an important topic in research and practice (Waller & Fawcett, 2013; Papadopoulos et al., 2017; Govindan et al., 2018; Bag et al., 2020; Hallikas et al., 2021). The advantages of data analytics approaches have been explored by researchers in the field of supply chain risk management with an increasing interest over the last 10 years, see Fig. 3. Based on the Scopus database (Accessed at 13.01.2022) a search query was iteratively formulated and resulted into 247 supply chain risk management articles applying forms of data analytics approaches

TITLE-ABS-KEY ((“supply chain risk” OR “supply risk” OR “supply chain resilience” OR “supply chain disruption” OR “supply chain incident” OR “supply chain uncertainty” OR “supply chain vulnerability”) AND (“text mining” OR “data mining” OR “machine learning” OR “artificial intelligence” OR “big data” OR “data analytics” OR “natural language processing” OR “geospatial analytics” OR

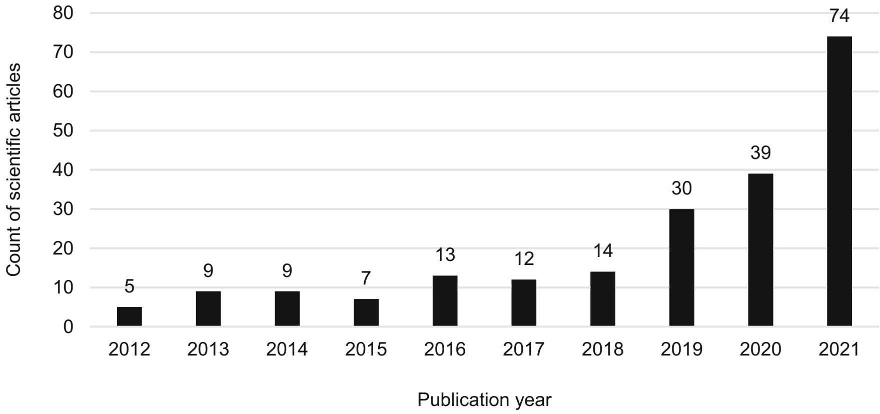

Fig. 3 Literature review on data analytics approaches in supply chain risk management

"geo spatial analytics" OR "geospatial intelligence" OR "neural networks" OR "neural network" OR "deep learning")).

Already in 2008 neural network approaches were proposed to improve supply chain risk management concepts (Teuteberg, 2008). He and Song (2009) analyzed the potential of knowledge discovery in databases to develop modules for early warning systems. To identify driving forces in supply chain risk categories, Moriizumi et al. (2011) developed a text mining approach analyzing scientific articles.

Since then, the research interest increased rapidly. Analyzing the articles two major research directions have been identified. On the one hand, research has been carried out to investigate the challenges of linking data analytics and supply chain risk management including the development of data-driven framework for decision support systems. On the other hand, data analytics approaches have been applied to several risk types to optimize operational processes.

Thus, Waller and Fawcett (2013) found that distributed data sources with heterogeneous data structures provide risk-relevant information for SCRM. Moreover, research has been conducted to structure the process from gathering, consolidating, and analyzing data to make informed decisions (Schlegel & Trent, 2014; Kang et al., 2017; Lee et al., 2017; Kara et al., 2018). Hassan and Passing (2021) published a concept for characterizing environmental, social, and governance risks to enable researchers and practitioners designing data analytics risk approaches.

Hassan (2019) utilizes machine learning and natural language processing to identify supply chain risks like explosions at supplier locations in news articles. Due to supply chain failures, bankruptcy on suppliers' site is a major risk for SCRM (Wiengarten et al., 2016; Iturriaga & Sanz, 2015; Zhang et al., 1999) applied neural networks to predict bankruptcies, while Barboza et al. (2017) used machine learning to predict bankruptcy. In 2015 Twitter has been considered an alternative data source to get further insights into supply chain issues (Chae, 2015). Handfield et al. (2020)

demonstrated the approach by converting large amounts of unstructured data into two measures, risk impact and risk probability. Fan et al. (2015) proposed a concept for integrating environmental risk data into supply chain risk management processes. Papadopoulos et al. (2017) however explored the role of big data by evaluating its influence on supply chain resilience. Therefore, they collect 36,422 risk event items from 2015 related to the earthquake in Nepal.

Although public warning systems can provide relevant data regarding environmental risks none of the analyzed approaches investigate the potential of public warnings for data analytics approaches in SCRM. Rather, they deal with specific types of risk, but these can be enriched and or supplemented using data from public warning systems. This is where our approach steps in to design a systematic approach to integrate public warnings into SCRM processes. Interesting research has been identified as conceptual basis referring to CAP, a standardized alerting protocol (see Oh et al., 2021; Rojas et al., 2018; Kwon et al., 2017; García et al., 2017; Bhandari et al., 2016; Rieser et al., 2015).

2.1 Concept for Integrating Public Warnings in Supply Chain Risk Management

Based on the reviewed literature we create a new conceptual model which integrates Public Warning Systems (PWS) and Supply Chain Risk Management (SCRM). While PWS includes the functionality of hazard detection and alert distribution (Niebla et al., 2016), SCRM contains four general steps (identification, assessment, mitigation, and monitoring) (Ho et al., 2015). The logical interface between both models is that PWS is an information producer that creates risk data and SCRM consume risk-related information which is a structured approach that matches risks and supplier. To integrate both models a geospatial approach is needed that bridges the unjointed data. Figure 4 furthermore shows that PWS notifies groups at risk based on their localization, while focal OEMs have in their internal supplier databases information about the localization of their supplier. Each information must be matched systematically to enhance sustainable supply chains.

Furthermore, it shows an extract of a geo-localized upstream supply chain, where a risk event occurs. The risk event could affect the supply chain and thus a network of companies working with each other. Taking the example of an earthquake, the USGS provides information about risk events. This information is outside of supply chain risk information systems. Published notifications, that implicit reference potential supply risk needs to be considered in the context of affected supplier. Thus, our approach addresses the identification of supply chain risk with data from public warning systems.

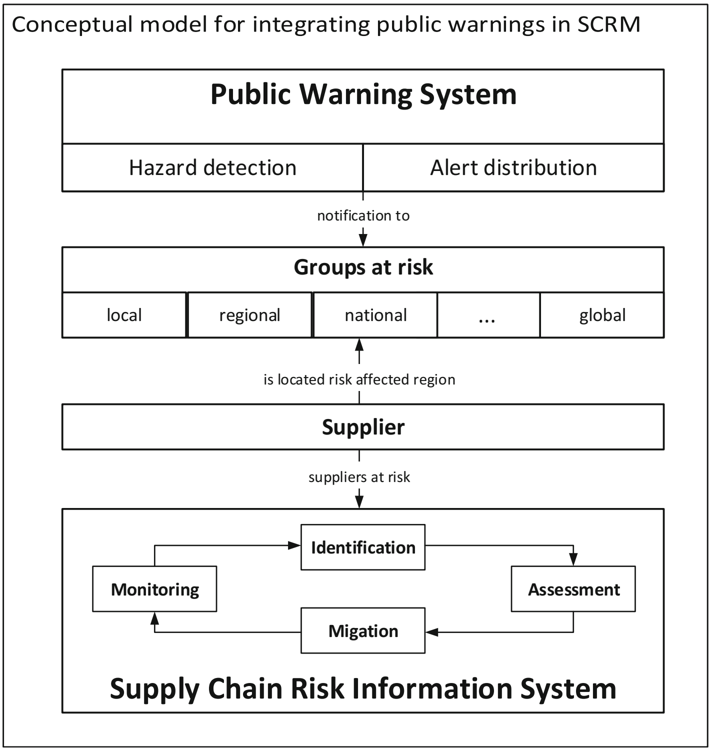

Fig. 4 Framework for integrating a PWS in SCRM processes

2.2 *Conducting a Data Schema for Mapping Supply Chains and Environmental Risks*

In this section we concretize our framework for integrating PWS and SCRM (see. Fig. 4) by conducting an integrated data schema model (see Fig. 5). We used CAP as basis for public warnings (CAP, 2012) and integrated common supplier database information (Zrenner et al., 2017; Cutting-Decelle et al., 2006). To enhance the data schema, we analyzed further schemas like A4A (Niebla et al., 2011) to identify relevant data features for our supply chain risk management approach. Figure 5 shows the result of our adapted data schema. It consists of four different entities alert, info, resource, and area. The alert object includes all general attributes of the risk notification. The info object describes the incident itself as well as the magnitude of the incident. The resource object references the resource and the area object references to an affected localization. It could have several types of representation. The geospatial reference could be a point, encapsulated as longitude and latitude, a circle, encapsulated as a point with radius or a polygon, encapsulated as sequence of points, where first and last points are the same.

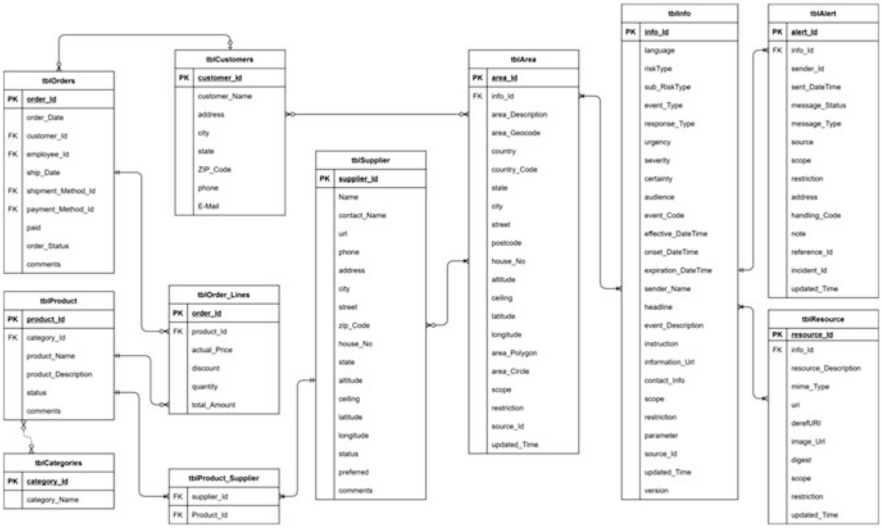

Fig. 5 Adapted CAP-SCRM schema for environmental supply chain risks

Beside public warnings, supplier master data must be reviewed to understand the challenges for a geospatial analytics method that performs a linkage between risk event and supplier. Zrenner et al. (2017) proposed a typical data schema of supplier and customer and their relationship. The supplier could be any company, which delivers parts to a customer (in this investigation an OEM). The supplier entity consists of several attributes. For this investigation, the most recent ones are attributes that disclose the location of a supplier. In general, the location information could be given textual, textual standardized (e.g., ISO codes) or geocoded (e.g., WGS84).

2.3 *Derivation of Functionalities for a Geospatial Supply Risk Identification Method*

Evaluating the integrated data schemas (see Fig. 5), a morphological box is defined, that specifies how supplier data and risk data is linked based on their geospatial attributes. Regarding the data characteristics Table 1 structures the required functionalities.

Func. 1. The first requirement will be derived from the scenario that the supplier location is stored textual, and the risk location as well. To link both data sets a string-matching method would be needed. Considering the example of Kinshasa and Brazzaville, we have two different countries and two different cities but just

Table 1 Required Linkage approach to identify risk-affected companies

	Risk location (e.g., form CAP)		
Supplier location		Textual	GPS
	Textual	Func. 1	Func. 3
	GPS	Func. 2	Func. 4

one river and approximately 5 km distance between both capitals.[1] So when locations are exactly the same string matching work out but since distances or nearby information could be equally important, it is necessary to geocode the textual information and transform them to geographical data.

Func. 2. The second requirement results from heterogeneity in data types. In the scenario that the suppliers' location is given in geographical coordinates and the risk location is formatted as textual data makes data harmonization necessary. Different from Func. 1 without feature transformation step, no linkage is possible.

Func. 3. When the supplier's location is textual and the risk location is in geographical coordinates, a data harmonization step is needed again. One possibility is to preprocess the data equivalent to Func. 2, the other possibility is to do a reverse geocoding for harmonize data to a textual representation. When both location data are represented textual measuring the string similarity and perform the record linkage based is possible.

Func. 4. Function 4 based on the scenario, that the suppliers' location is represented as geo coordinates and the risk event is also associated to geo coordinates. Like in Function 1 in this case no preprocessing step is needed. Both data are represented numerical, which means that mathematical operations could be performed to link a risk event to supplier location. By reviewing the public warning there are three possibilities in which the location of the risk event could be represented, for example, (i) in case of an earthquake as a point, (ii) in case of a hurricane as a line or according to WGS84 as list of single points, or (iii) in case of flash flood as a polygon or according to WGS84 as a list of points where the first and last points must be equal to determine the end of the polygon.

3 Model for Enhancing SCRM with Geospatial Risk Matching

When looking at the four described scenarios as well as the required functions, we can summarize that there is a high overlap and a dominance of the geospatial operation compared to the textual operation. Consequently, textual geographic information must be transformed into geo-coordinates. The four extracted requirements define three main elements encompassed by the conceptual model. The first element is public available risk data, the second element is the internal available

[1] https://www.google.com/maps/@-4.2947686,15.2865633,13.94z

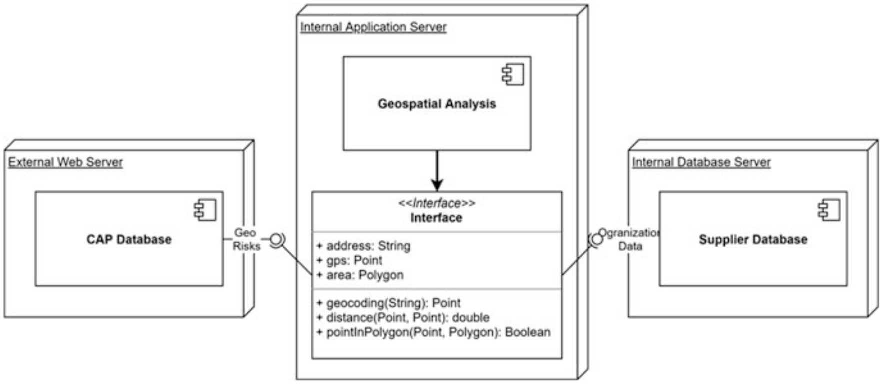

Fig. 6 Model for matching public warnings with supplier data

supplier data and the third and binding element of the concept is the geospatial linkage engine, which works with distances and geospatial operations. The distance will be measured along the surface of the earth, taking its curvature into account. Figure 6 illustrates these three elements on logical format. The geospatial risk linkage engine contains three operations for linking a risk event to a supplier.

If a risk event is given as a geographical coordinate, a point-to-point distance calculation is necessary. The threshold t determines if a public warning is associated with a supplier or not. If the point-to-point distance d is smaller than t the public warning is also a potential supply risk for a focal OEM. The distance between two points ($p_1 = (\lambda_1; \varphi_1)$ and $p_2 = (\lambda_2; \varphi_2)$) will be calculated by the *haversine* formula (Sinnott, 1984):

$$d = R * c \tag{1}$$

where R is the radius (6371 km) of the earth and c is defined by:

$$c = 2 * atan2\left(\sqrt{a}, \sqrt{1 - a}\right) \tag{2}$$

where a is defined by:

$$a = \sin\left(\frac{\Delta\varphi}{2}\right) * \sin\left(\frac{\Delta\varphi}{2}\right) + \cos(\varphi_1) * \cos(\varphi_2) * \sin\left(\frac{\Delta\lambda}{2}\right) * \sin\left(\frac{\Delta\lambda}{2}\right) \tag{3}$$

where φ is latitude and λ is longitude. Another calculation method that would be a suitable approach to determine the distance is the spherical law of cosines. However, taking the example of a hurricane, the public warning could be given as a line with a start and endpoint, in that case, the point to line distance will be measured to link a supplier location (s) to the risk event (*riskStartGPS rs, riskEndGPS re*). The calculation must be extended by the bearing (Θ) of s to rs and rs to re:

$$\theta = \text{atan2}(\sin(\Delta\lambda) * \cos(\varphi_2),\ \cos(\varphi_1) * \sin(\varphi_2) - \sin(\varphi_1) * \cos(\varphi_2) * \cos(\Delta\lambda)) \quad (4)$$

Then the distance between s and rs must be calculated as described above. Then the three results will be transferred to the cross-track distance formula, which is defined by:

$$d_{s;\,rs,re} = \text{asin}\left(\sin\left(\frac{\delta_{s;\,rs}}{R}\right) * \sin\left(\theta_{s;\,rs} - \theta_{rs;\,re}\right)\right) * R \quad (5)$$

where δ is the angular distance from supplier location to the coordinates of the start point from the risk event. Taking the example of a flood the risk-affected area could be represented as a polygon. A polygon is defined as a sequence of point, where the first and the last one is connected by an edge (Haines, 1994). In this investigation, a point is a geo coordinate, which represents the supplier's location, and the polygon is the risk-affected area. Regarding this, a point in polygon calculation is required. There are several strategies for testing to meet this requirement. It will be calculated by the crossings test algorithm (Shimrat, 1962):

```
timesCrossed ← 0.
FOREACH riskBoundary IN riskPolygon:
IF ray_inters_seg(supplierlocation, riskBoundary) THEN
timesCrossed ← timesCrossed++
IF is_odd(timesCrossed) THEN
RETURN insideRiskPolygon
ELSE
RETURN outsideRiskPolygon
```

4 Prototyping and Evaluation

In this section, the development of a prototype and the insights from its evaluation demonstrate the potential of the conceptual model for integrating public warning into the SCRM. Before the data sources and its collection are discussed, the technology selection and the components of the prototypical instance are described. Finally, three evaluation cases are presented, evaluated by feedback from qualitative interviews with domain experts.

4.1 Prototypical Instance

The prototype is an instance of the conceptual model for supply risk identification. It should be understanding as an artifact, that demonstrated the ability to solve the identified functions and requirements (Sect. 3). Figure 7 gives an overview of the

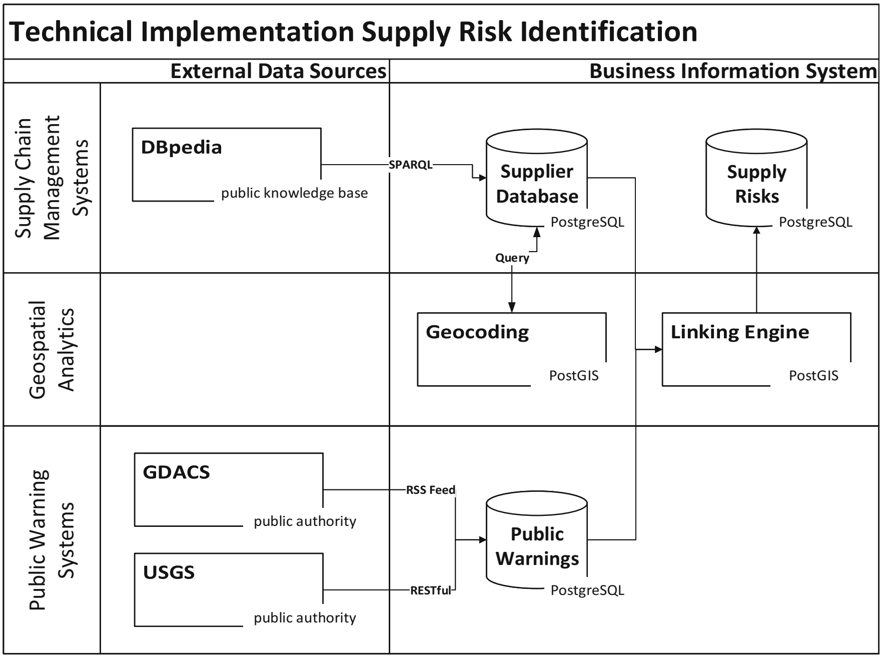

Fig. 7 Model of a prototypical instance

implementation and shows how the different components will be instantiated to utilize geospatial analytics for SCRM. To demonstrate a supplier data base company data are extracted from DBpedia and enrich geocoordinates by geocoding. To simulate SCRM we query data from USGS and GDAC and store them in a PostgreSQL instance. Within the PostGIS instance, we measure and match the independent data source and as risks in PostgresSQL instance.

4.2 Data Collection

This subsection describes which data are used for evaluating the prototype. To guarantee traceability, publicly available supplier data are extracted from DBpedia, and risk data are extracted from the Global Disaster Alert Coordination System (GDACS) for testing and from the United State Geological Survey (USGS) for generalization. All data sources are freely available and can be queried by means of a web interface. Supplier location data from DBpedia.

The automotive supplier location data are queried through the public available DBpedia[2] web endpoint for the supplier location of Spartanburg (United States),

[2] https://dbpedia.org/sparql

Chennai (India), and Rosslyn (South Africa). Moreover, the area of the southwest of United States has been used for the chemical industry test case. Environmental Risk data.

GDACS is based on a cooperation framework from the United Nations, the European Commission, and disaster managers. It aims to improve alerts, information exchange, and coordination in the early phase after major sudden-onset disasters. To fetch public warning a feed reader parses CAP data from GDACS.[3] Like introduced in Sect. 3 CAP instances are structured in XML. To extract the relevant information from the CAP feed XPATH queries must be performed.

A second data source from an information generator and alter message author (see. Fig. 1) is used to generalize our approach. Taking the example of earthquakes, the USGS as US authority provides risk data that are publicly available in the web USGS (2022). USGS hosts a RESTful interface to have access to earthquake data. In this investigation, the API version 1.12.3 is used. Within 10 years between 2012 and 2021 the data source returns 1393 earthquakes with a significant impact magnitude (greater than or equal to six).[4]

4.3 Demonstration

Case Study: Detailed Environmental Risk Event—Extreme Weather (Super Typhoon Jebi in Japan)
According to the World Economic Forum Global Risk Perception Survey 2021–2022 extreme weather is the second most serve risk on a global scale over the next 10 years. Figure 8 shows a historical tropical storm (named Jebi) from September 2018 in Japan. The environmental risk hits an industrial area where several automotive supply chains (e.g., Denso Corporation, Topia Co. Panasonics Corporation, Circuit Design, Japan Radio Co., Johan Manufacturing) are localized. Beside the geo-coordinates, a summary of the risk event is given. It says that with 260 km/h the typhoon is growing to a super typhoon and that more than 20,000 people have been evacuated due to the heaviest storm in 2018. Following Ho et al.'s (2015) requirement that SCRM approaches must integrate multiple risk management steps, the case study shows that in addition to risk identification step, the risk assessment step is also supported. Once a risk has been identified, the dynamic slider can be used to adapt the damage radius to assess different hazard scenarios. In the scenario shown, six automotive suppliers are affected by the environmental risk. The prototype was presented to various procurement experts from the German automotive industry based on their feedback the model from Fig. 6 must be extended. From a practical perspective the supply risk database must be linked

[3] http://www.gdacs.org/xml/gdacs_cap.xml

[4] https://earthquake.usgs.gov/fdsnws/event/1/query.geojson?starttime=2012-01-01%2000%3A00%3A00&endtime=2021-12-31%2023%3A59%3A59&minmagnitude=6

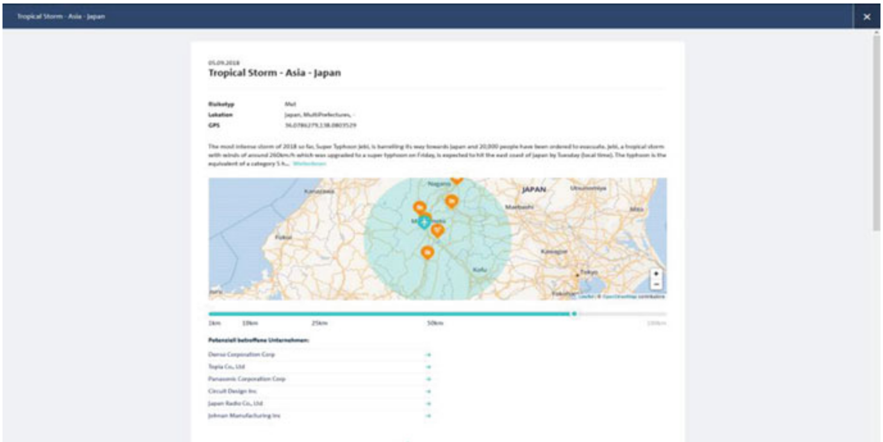

Fig. 8 Demonstration of identifying risk-affected supplier by applying geospatial analytics to enhance SCRM

over the supplier identification (DUNS no.) to other procurement systems to ensure a better SCRM. If the DUNS no. is identified it will be possible to measure incoming goods, order volume and inventory range and assign the KPIs in an aggregated manner to the risk event or on a detailed level to the supplier.

Case Study: Industry Specific Risk Profile—Environmental Risks in the Chemical Industry

According to the World Economic Forum Global Risks Perception Survey 2021–2022 human environmental damage is the fourth most severe environmental risk on a global scale over the next 10 years. In our first case study, we demonstrated how our approach can be used to enhance SCRM of ad-hoc environmental risks. In the second case study, we demonstrate how our approach enhances the SCRM of latent environmental risks. Using our geospatial analysis approach, we created risk profiles based on historical risk data. The deducted risk profiles support to assess a risk potential of a specific region or industry. Figure 9 shows the occurrence of chemical explosions as environmental risks in the US West coast. To generalize the insights from our investigation we harvest explosion data from USGS and additionally crawled sustainability controversies that are associated to the chemical industry. By doing so we demonstrate that publicly available data support SCRM and contribute to the requirement of Waller and Fawcett (2013) who request to explore the direct connection between Big Data Analytics and SCM. We present our results on the Achema conference 2021[5] to an audience of domain experts from the chemical and automation industry. Beside positive feedback on the insights for SCRM, we had an important discussion regarding possible misconceptions. To

[5] https://www.achema.de/

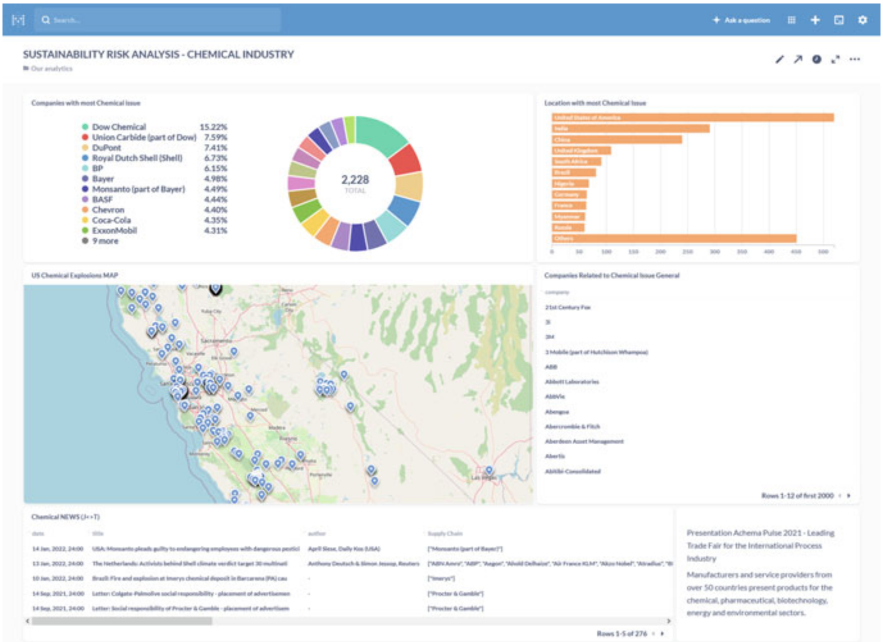

Fig. 9 Analysis of risk exposition by applying geospatial analytics on geo-based chemical industry

avoid ethical failures, metrics must be interpreted carefully in the appropriate context. For example, the dashboard shows the USA as the country with the highest number of sustainability controversies. However, it should not be inferred without further elaboration that the USA actually has the most risks. In addition to a factually increased risk exposure, the ranking may be due to differences on data availability per country or a lack of normalization of risk cases in an industry or in a country and the country-specific size of the industry.

Case Study: Location Specific Risk Profile—Environmental Risks in the Automotive Industry
Our third case study reflects the analysis of location-specific risk of supplier or manufacturing facilities. Many companies nowadays encounter sustainability in their overall business and supply chain strategy. However, global thinking requires local actions for sustainable supply chains. Using our geospatial analytics approach focusing on three manufacturing facility locations of the automotive OEM BMW in Spartanburg (USA), Chennai, (India), and Rosslyn (South Africa), historical environmental risk data from USGS was mapped (Fig. 10).

Analyzing the three different manufacturing facility areas of BMW, location-specific risk profiles can be carried out. Thus, for instance, Rosslyn has been several times affected by floods in 2020 and 2021, whereas Chennai was last affected by floods in 2016. Spartanburg on the other side has not been affected by environmental risks in

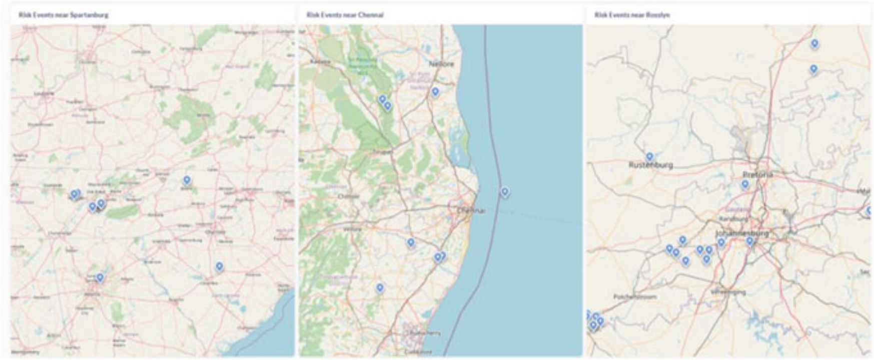

Fig. 10 Demonstration of the analysis of risk potential of a supply chain location

the last decade. Taking these measures and insights into account actions regarding supply chains and projects for the society in that region can be better decided due to the enhanced information. Proposing this approach positive feedback was given by sustainability and supply chain experts. Experts further recommended integrating forecasting measures regarding these environmental risks to foresee possible scenarios and develop long-term actions.

5 Conclusion

The investigation demonstrates that environmental risk data is publicly available and has an impact on sustainable supply chains and its management. Our presented approach illustrates how to link external and internal information for an enhanced supply chain risk management taking environmental risk into account. The following section summarizes the results of the findings by answering the research questions and providing an outlook for further research.

6 Contribution

This investigation contributes to the requirement that prototypes combining data analytics and SCM need to be explored (Waller & Fawcett, 2013). Moreover, requirements for SCRM frameworks must be validated empirically to proof the applicability of SCRM methods (Ho et al., 2015). Within our investigation, we identified a research gap in the convergence of public warning systems for environmental risks and supply chain risk management. Our data analytics approach by the means of geospatial analytics demonstrated its practical feasibility toward sustainable supply chains and supply risk management processes. Thus, our research questions can be answered as followed:

- RQ1: What are the essential requirements for linking public warnings to the supply chains?
  - By reviewing literature in the fields of SCRM, Sustainability and big data analytics, we identify the requirement for linking public warnings and supply chains. We design an integrated model which bridges SCRM and public warning systems (see Fig. 3) and specifies argumentative deductive four functional requirements and deduct functions to link public warnings and SCRM to identify supply chain risks (see Table 1). The description of needed functionalities also contributes to the revealed research gap from Waller and Fawcett (2013) as well as Ho et al. (2015).
- RQ2: How can a conceptual model of an artifact be designed, to identify environmental supply risk based on public warning data?
  - Since public warnings are high-quality and reliable risk data, linking them to supplier database with geospatial analysis is an important step to enhance SCRM. With the common alerting protocol, we identify a standard that provides public warnings to different groups of society. Like different countries specified own CAP derivates, we show how to extend the standard (CAP 1.2) to use it in SCRM (see Fig. 4). Based on the newly designed data schema, we developed a component diagram that contains all software fragments which are necessary to bring the entities together (see Fig. 6).
- RQ3: What might a prototypical instance of the conceptual model look like?
  - We contribute several IT artifacts; an architecture model of the implemented instance is showing an end-to-end data flow from external and distinct data sources to integrated and linked data sources. Furthermore, we depicted with which technologies we implement our technical instance, which helps researchers and practitioners to reproduce our solution and results (see Fig. 7). This investigation proves and contributes an approach that shows how to identify potential supply risks by analyzing two independent data sources. The consideration of earthquakes from USGS shows great potential from a quantitative point of view. While no threshold is applied, USGS reports in the year 2021 161.379[6] public warnings. Processing these potential supply risks without linking engine is time exhaustive and inefficient.

6.1 Outlook and Discussion

To fully assess the potential of the designed artifact, a comprehensive case study– using different public warning data sources—must be carried out. The prototype is not designed as a productive system. To integrate the artifact into a productive environment it is necessary to build an interface to the business information system

[6] https://earthquake.usgs.gov/fdsnws/event/1/count?starttime=2021-01-01&endtime=2021-12-31

and to the supplier database. Since corporate supplier data are usually confidential, automotive supplier data from DBpedia are used in this study. This circumstance goes hand in hand with the limitation that no associated supplier transactions can be evaluated for a risk assessment.

Another aspect is the metric of relevancy. The quality of identifying potential supply chain risks hinges on the parameterizing of the threshold. To achieve a well-performing threshold, it will be necessary to execute case studies with domain experts, who are able to define a heuristic for threshold optimization.

Upcoming investigation which addresses the lack of supply chain visibility (Christopher & Lee, 2004) will have a significant impact on the general performance of the presented approach. As a more n-tier supplier and their relationships to an OEM are known, more supply risks can be identified.

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Extending Common Alerting Protocol (CAP) System to Disseminate Extreme Weather Warnings to a Wider Population in Tanzania

Victor Massam, Fatuma Simba, and Ruthbetha Kateule

Abstract Extreme weather warnings are required to reach a vast population to save many lives and protect livelihoods. However, the existing extreme weather warning systems rely on internet-based feeds, which cannot reach the wider population in developing countries especially Tanzania where many areas have limited internet connectivity. This research proposes a Common Alerting Protocol compliant extreme weather warning system for broadcasting networks in Tanzania to disseminate the extreme weather warnings messages to a broader coverage. This chapter describes the design and implementation of a proof-of-concept prototype, which managed to disseminate the extreme weather warning to a large population via mobile cellular phones and TV broadcasting stations. Group discussion observations and document analysis were employed to gather primary and secondary data to determine requirements for the extension. The effectiveness of the prototype was evaluated based on mobile phone and auto broadcasting which shows that 91.5% of SMS was successfully delivered for less than a minute and a video clip of 13.5 MB was successfully sent and interrupted in the ongoing TV session at a broadcasting station.

Keywords Common alerting protocol (CAP) · Extreme weather alerts · Early warning systems · Extended CAP protocol

1 General Introduction

Standard Common Alerting Protocol (CAP) is an internet-based system that uses eXtensible Markup Language (XML) to channel information (WMO, 2018). CAP is an international standard format for emergency alerting and public warnings such as earthquakes, volcanoes, public health, power outages, drought, heavy rainfall, extreme temperature, storms, heavy lightning, and tsunamis (WMO, 2010). Extreme

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weather information is required to reach the intended audience before an event occurs to save lives, livelihood, and assets. Several systems with CAP properties are used in extreme weather warning dissemination around the world, for example, the Meteo-alarm system is mainly used in Europe for disseminating severe weather alerts, Google Public Alerts and Wireless Emergency Alerts (WEA) are the main channels in the USA (Bala & Arjun, 2015). AccuWeather is a unique partnership to deliver global extreme weather warnings and is made up of an improved CAP protocol with the package of a complex dynamic website, smartphone apps as well as streaming video broadcasts. Any interested country can register and use such a service. Currently, the system is available in more than 40 countries, including real-time online videos (Accuweather, 2019).

Many developing countries especially Tanzania use Standard CAP to warn citizens about extreme weather events (Eliot Christian, 2019), Such a CAP system is less effective as it works in the form of news feeds and users are required to subscribe to get information. However, many people are not subscribing to CAP, thus information rarely reaches the vast population at the desired time (Câmara et al., 2010). This is because most of the targeted people in Tanzania do not have access to the media which broadcasts the information. Therefore, there is the need to extend the coverage and access of CAP by incorporating mobile and television (TV) broadcasting media since mobile devices and televisions are the most frequently used and most important sources of both local and national news (TCRA, 2018).

Nonetheless, very little is known about how to use mobile phones and TV broadcasts to simultaneously alert a wide population about extreme weather events. Consequently, this study proposes an extension of the Tanzania Meteorological Agency (TMA-CAP) Tanzania Broadcasting Corporation (TBC) system using regular SMS to mobile phones and TV broadcastings. In a TV broadcast, weather information is supposed to automatically interrupt an ongoing TV session so that people are timely aware of the potential danger. For mobile users, extreme weather information is required to reach their mobile phones as SMS on time. To meet this objective, this study gathered and analyzed requirements for extending the CAP system, redesigned the prototype, and came up with an extended CAP architecture to be used for implementing extension features as well as evaluating the capability of the implemented prototype in disseminating the extreme weather.

The remainder of this work is structured as follows. Sect. 2 analyzes the related work. Sect. 3 presents the methodology. Sect. 4 presents the findings deduced from focus group discussions and document analysis. Sect. 5 describes the architectural design of the extended TMA-CAP. Sect. 6 presents the prototype implementation, and the evaluation of the prototype is demonstrated in Sect. 7. Finally, the paper ends with the conclusion in Sect. 8.

2 Related Work

According to Eliot Christian (2019), several countries have attempted to extend the CAP system for various reasons as follows. In Italy, CAP was extended to disseminate real-time extreme weather warnings from hot-spot detection in real time by satellite imagery. Satellite observes extreme weather alerts and relays the information to the public through smartphones. The satellite information is communicated to smartphones via the internet. Similarly, information can also be transmitted to computers via browsers. In Taiwan, CAP Implementation with social media for users of the public internet, 4G telecom, Internet of Things. Social media has a One-Stop Alert Platform that handles 36 types of alerts from different agencies that issue alerts. CAP and Google Public Alerts, CAP was extended to Google platforms and terminal devices that support Google play services such as Google Web, Android smart devices, and Google maps. Security enhancements were also considered when certificates to the user were freely installed via the Google Chrome browser. Meteo-Alarm extended CAP to cooperate with a dynamic enabled GIS website and a framework that includes more than one member country from the European Union and can include more than one hazardous (Weather, Geo, Floods, etc.) and different languages as well. They are now in the design phase to extend it to MQTT protocol as the standard messaging protocol for the Internet of Things (IoT). CAP in Brazil, extended by Merging Meteorological and Disaster Alerts, spans in web weather alerting portal with three centers at the national level: National Institute of Meteorology (INMET), National Centre for Monitoring and Early Warning of Natural Disasters (CEMADEN), and the National Centre for Disaster and Risk Management (CENAD). CAP is used as these different centers perform their separate roles. INMET is the national institution responsible for weather forecasting. CEMADEN oversees continuous monitoring of conditions indicating imminent risk of landslides, floods, and severe droughts. Any early warnings are then reported to CENAD, which retransmits them to the state and municipal departments of Civil Defense. CAP in Canada was extended to Wireless Public Alerting, which is the National Public Alerting System (NPAS), based on CAP, which pushes alerts to the public through TV and radio and to wireless devices through cell broadcast. Canada chose Nokia as the cell broadcast provider primarily to align alerting. The device must be geo-location configured for location updates and thus ensure receiving information based on the location during the movements. In Zimbabwe, the Meteorological Services Department of Zimbabwe (MSD) extended the CAP System to include a feature for social media such as WhatsApp to suit the needs of social media users. The system enables them to integrate and share information from the CAP system to users subscribed to organizational social media groups (MSD, 2017). In Germany, CAP has been extended to an automatic sense emergency, which generates warning information through the internet. In the Philippines, the CAP system has been restructured to include polygon, geocode, and area description in each area. In Norway, the Norwegian Broadcasting Company extended CAP using the Application Programming Interface (API) for video and audio. In the new model, the internet is used to send content for broadcasting. In Mexico, the CAP system was extended to a new system known as Mexican Seismic Alert System, controlled by SASMEX sensors used to detect extreme events (Allen & Melgar, 2019). The new system activates loudspeakers in the streets, video surveillance cameras, and radio receivers in buildings and public schools. This has expanded to reach people who have neither mobile phones, web (internet) nor televisions.

Several extensions have been applied in CAP systems including the addition of real-time satellite images, social media, GIS-enable added functionality, Application Programming Interface (API) to mass media, dynamic website and smartphone's app, live streaming video broadcasts, and loudspeakers, displays (billboards), and cameras in the streets. Nonetheless, none of the extensions has focused on the simultaneous use of regular GSM mobile to convey warning SMS and the use of television broadcasting channels to extend CAP. This study, therefore, bridges the gap on how to relay severe extreme weather alerts to mobile phones through SMS and how to make extreme weather alerts interrupt an ongoing television broadcast. The intention is to come up with a prototype that reaches a broader population, and thus, enhances the warning mechanism against extreme weather in the context of many developing countries.

3 Methodology

The research applied a qualitative approach and waterfall model SDLC to develop a prototype of an extended TMA-CAP system. The questionnaire was designed following a review of existing work in the field as shown in the Appendix. In developing the questionnaire, the researcher adhered to the research questions posed by the study. Likewise, the study used focus group discussion and document analysis to obtain information. Four institutions in Dar es Salaam Tanzania were selected as areas of study, i.e. Tanzania Meteorological Agency TMA, Tanzania Broadcasting Corporation (TBC), Tanzania Communications Regulatory Authority (TCRA), and e-Government Authority (EGA). TMA is an agency responsible for providing meteorological services in Tanzania. TBC was chosen because of its role as a corporation for TV broadcasting to the public. EGA is an agency that paves the way for mobile phone operators to disseminate information to channels. TCRA was included because it substantiates telecommunication coverage in Tanzania. The UML (Gomaa, 2006) and informal notation have been used for designing. Furthermore, the Waterfall Model of SDLC was used to implement the prototype.

TMA, as the source of information, sends data to TBC for broadcasting. The study, thus, focused on how the extreme weather warning can automatically be disseminated from TMA to TBC broadcasts; by interrupting an ongoing TV session and how special alerts via SMS are sent to mobile phone users. Mobile phone numbers used in this evaluation were derived from TMA documentation in Mwanza and Arusha. The numbers were randomly selected from five popular network operators in Tanzania, namely, Vodacom, TTCL, TIGO, Airtel, and Halotel. The

UML (Gomaa, 2006) and informal notation have been used for designing. Furthermore, the Waterfall Model of SDLC was used to implement the prototype. One thousand cellular mobile phone numbers were used for testing the dissemination capability of the extended CAP in warning the audience about extreme weather via cellular mobile phones. The list of mobile phone numbers was obtained from the TMA database that is currently used for disseminating information to farmers through regular modems. TBC was purposely selected for broadcasting purposes for direct accessibility. Likewise, an alerting video clip was tested at a broadcasting channel.

4 Findings

From the focus group discussions and document analysis, we could see that for a large population to be alerted by using current TMA-CAP, extension is required to include both Television and Cellular mobile users. and, further, more TV alerts require auto broadcasting and interrupt ongoing sessions, and Mobile alerts require smart notifications. This is deduced from both primary data and secondary data as summarized in Table 1 and the required functionalities of the proposed CAP system as summarized in Table 2. Table 1 summarizes the responses from the focus group

Table 1 Responses from respondents

Place	Responses
TMA	Manuals, e-mails, and CAP feeds which are used to disseminate information by TMA should be complemented with other means for the CAP system to relay adverse weather information to more people. The information should be prioritized to reach the audience as quickly as possible. The need for the effective utilization of the available telecommunication infrastructure to enhance the dissemination of extreme weather warnings.
TBC	TBC receives information for broadcasting through e-mail; video clips are sent by reporters through smart devices and file transfer protocol. TBC has a digital broadcasting system.
EGA	There are redundant SMS services linked to all mobile operators in Tanzania via API. SMS from any government organization is channeled directly to the mobile operator (s) for dissemination. Composed SMS from any government sector (e.g., TMA) goes directly to the mobile operator(s) for dissemination. There is no queue of messages between the government organizations and mobile operators because EGA just acts as a gateway (EGA, 2018). Processing engines belong to mobile operators. Only a regular SMS. There is a possibility to set SMS priority of SMS according to their sensitivity to the public.
TCRA)	According to TCRA (2018), there is a fast growth of mobile services in Tanzania, especially in rural areas, Tanzania had a mobile penetration rate of 81% in December 2018 and 43% internet accessibility. Television and radio broadcasting cover up to 91% of the Tanzania population; thus, there is a need to take advantage of the benefits offered by mobile and TV devices to reach most of the population.

Table 2 Required extensions

Requirement	Current CAP	Extended CAP
TCP/IP protocol to spread information to web users	Yes	Yes
Notification via RSS feeds on the internet	Yes	Yes
Directly integrated mail list for notification purposes	No	Required
The promotion of e-mails that are not registered in the system	No	Required
The embedment of social media capability	No	Required
The integration of cellular mobile phone users broadcast module	No	Required
Sending information to broadcasting stations for rebroadcasting	No	Required
Making the GIS module show an area with expected effects	Yes	Yes
Interrupting an ongoing TV session	No	Required
Alerting standard	Yes	Yes
Smart notifications (desktop and smart devices users)	No	Required

discussions per institution regarding current working procedures; how the information could reach a large population, based on the devices they used; challenges of the existing CAP system and other study areas to improve dissemination.

A careful examination of the issues raised by the selected institutions summarized in Table 1 reveals that the proposed CAP system requires the following extensions as summarized in Table 2.

5 Architectural Design of Extended TMA-CAP System

The proposed TMA-CAP system was designed based on the requirements specified in Table 2. The extension of the TMA-CAP was based on the existing systems and infrastructures, i.e., existing TMA-CAP, mobile telecommunication system, Television Transmission (Broadcasting), and Internet connectivity. The design focused on SMS-based alerts as well as automatic TV broadcasting. The design involved the UML and informal diagram notations: use case diagram, state-chart diagram, deployment diagram, extension architecture, and processing logic design.

5.1 Entity-Relationship Diagram

For the extended TMA-CAP system to accommodate both cellular mobile and TV broadcasting, Fig. 1 describes classes, their associated relationships, and functions. The broadcasting centre (TBC) broadcasts specific information to the broadcasting station. Next, the broadcasted information is disseminated to more than one station. In the case of the mobile cellular user, the user is identified by location, after which one content of SMS has to be disseminated to all registered mobile phones in that

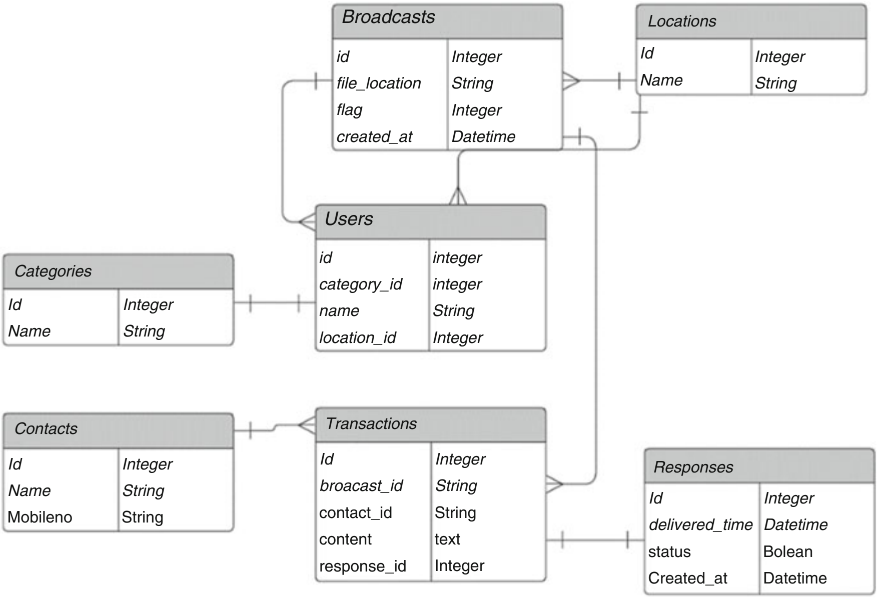

Fig. 1 Entity-relationship in both cellular and broadcasting dissemination

selected location. Moreover, SMS status is kept in class Response to keep track of and for evaluation purposes.

5.2 Use Case Diagram

In a use case, users interact with the system. They create information (TMA), send it, and manage the system. Broadcasting stations such as TBC receive information. Likewise, mobile cellular users receive information without login into the system too. A detailed description of the use case diagram is shown in Fig. 2.

5.3 State-Chart Diagram Design

The extended TMA-CAP system has been redesigned to have three states namely idle, intermediate/transition, and the final state as shown in Fig. 3. The ideal state is when the system is waiting for a new alert from both mobile and TV modules. Once there are extreme weather events, the system changes to an intermediate state where it initiates the dissemination process of the extreme weather warning. The enhanced feature for both SMS and broadcasting will always check for the news alerts and disseminate them if any. The final state starts when the dissemination process has

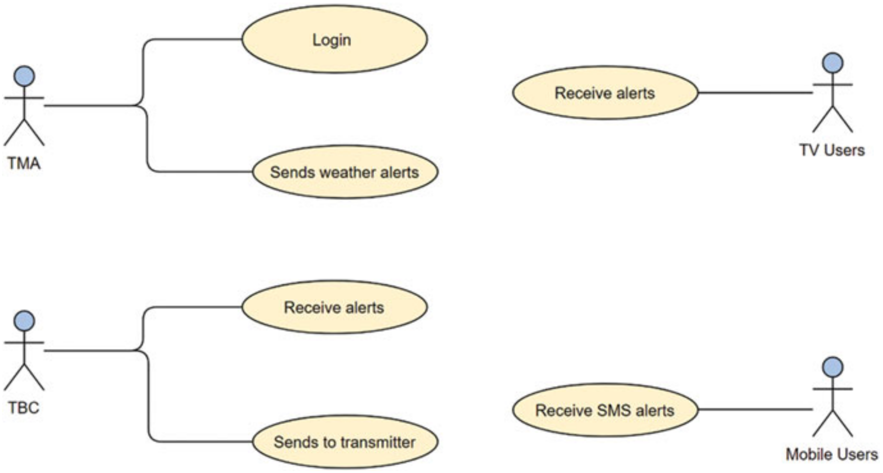

Fig. 2 Use case diagram showing the interaction between the user and the system

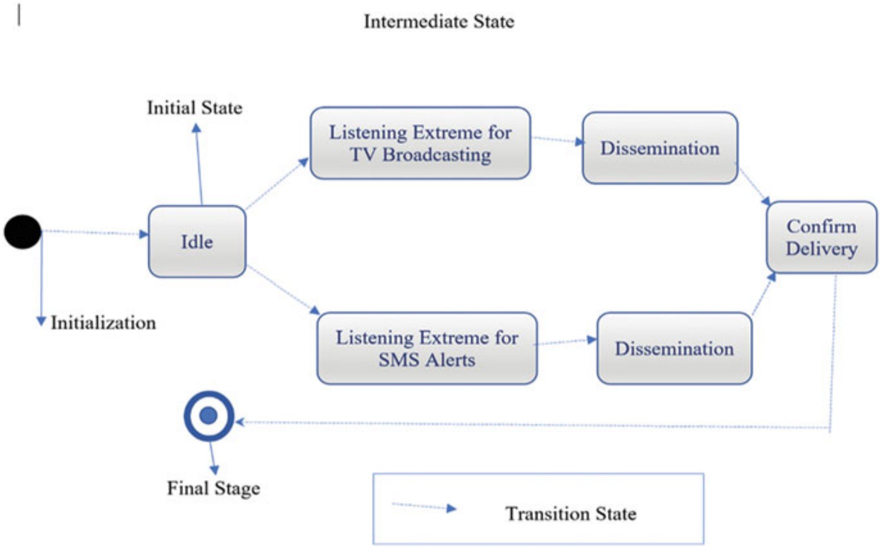

Fig. 3 State-chart diagram—showing system states from initial to the final state

finished, and the intermediate/transition state is when the system moves from one state to another.

5.4 Processing Logic Design

Figure 4 describes the general processing logic for an extended TMA-CAP system. The logic comprises web users, mobile users, TMA, broadcasting stations, and televisions. In the case of TV broadcasting, the broadcast table has a flag field, which has 0 default value; once new broadcasts are inserted, the flag value possesses value 1 in which the system checks for value 0, upon identification it interrupts an ongoing session and plays the weather alert in question. After finishing, it updates the value 1 and rolls back to 0 as old broadcasts. For cellular mobile alerts, the processed information is disseminated via the available government mobile platform and by region.

6 Prototype Implementation

The software architectural prototype of the TMA-CAP system has been developed based on the software architecture described in Sect. 5. This section describes such a prototype of that system with the functionalities focussing on the alerting of extreme weather events via TV and mobile phone users.

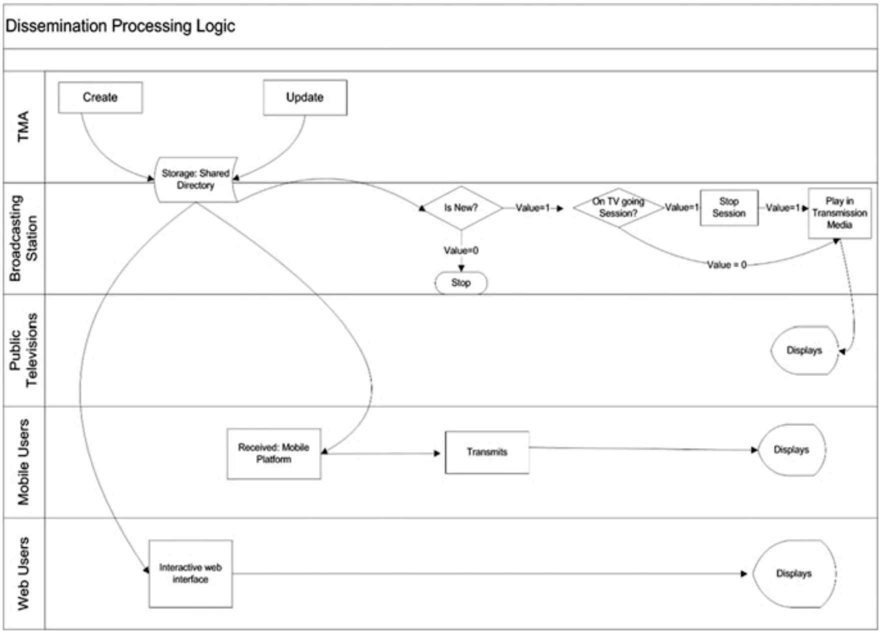

Fig. 4 Designed processing logic for extended TMA-CAP

6.1 Extreme Weather Alert via TV Broadcasting

Any Web user(s) of the system is authenticated, i.e., must be registered. The sender of the alert must log in to the system to enable them to use internet protocol and an integrated interface to disseminate information to both mobile phone users and TV broadcasting stations. For the extreme weather warning from TMA to be broadcasted to any broadcasting station, the shared directory at the public server has been created at http://tma.go.tz/ as shown in Appendix 2, Fig. 5. The system tends to check for new information every 2 s and auto broadcasts as shown in Appendix 2, Fig. 6. It further shows the time taken for information to be broadcasted via transmission system at broadcasting stations. For the automatic interruption of an ongoing TV session, the system set a default value of 1. Once there is new broadcasting information, it turns to 0 which denotes a new alert. After broadcasting, it returns to 1. Extended CAP checks for new information every 2 s.

6.2 Extreme Weather Alert via Mobile Phones

The Government of Tanzania has a Mobile gateway for disseminating information directly to a mobile operator(s) by allowing any composed SMS from any government sector (e.g., TMA) to go directly to the mobile operator(s) without staying in a queue. This prompts the possibility of setting SMS priority for the dissemination of the information to the public in the gateway. The gateway is utilized to quickly send SMS to 58 million people with mobile phones. The Weather Warning Department integrates with mobile telecommunication companies for sending SMSs directly to mobile phone users. Weather alerting features are also embedded in mobile cellular phones. Since the user is recognized by location, the function shown in Appendix 2, Fig. 7 sends SMS contents to multiple users depending on the registrations; it further reports SMS status and time of delivery for evaluation purposes. Appendix 2, Fig. 8 demonstrates the identification of the new user that is associated with his location.

7 Evaluation of the Prototype

According to MFAD (2019), general criteria for the evaluation of a prototype are relevance, efficiency, effectiveness, impacts, sustainability, connectedness, coherence, and coverage. The extended TMA-CAP system was evaluated along some of these criteria to check whether it relays relevant information to broadcasting stations and whether it can interrupt an ongoing TV session on time. The evaluation also involved its effectiveness in delivering SMS to cellular mobile phones.

7.1 Evaluation of the Relay of Alert to TV Broadcasting

In TV broadcasting, a video clip of 13.2 MB file size, containing the extreme weather warning was sent to a shared public directory between TMA and TBC. On receipt of this video clip, the ongoing broadcasting session was interrupted and played the video with extreme weather information for 29 s. A test for interrupting an ongoing TV session was, therefore, a success. Appendix 2, Fig. 9 shows the time at which the video was successfully shared and the time of broadcasting.

7.2 Dissemination of Weather Warnings via Mobile Phones

This evaluation involved 1000 mobile phone users from Arusha and Mwanza regions in Tanzania. The aim was to determine the effectiveness of the extended system in reaching as many mobile phone users as possible. Accordingly, a message was sent to all 1000 users chosen for the test. The results show that 4 SMS failed, whereas 996 SMS were successfully delivered to the users. The success rate was 99.6%, and the failure rate was 0.4% as demonstrated in Appendix 2, Fig. 10.

8 Discussion

Several countries have attempted to extend the CAP system for various approaches. This study extends the coverage and access of a CAP system by incorporating mobile and television (TV) broadcasting media since mobile devices and televisions are the most frequently used and most important sources of both local and national news. To accomplish this, the study first gathered and analyzed the requirements of the CAP system, redesigned and evaluated the proposed CAP system. In the evaluation phase, the extreme weather alert was sent to TBC in the form of a video clip; and it successfully interrupted an ongoing TV session for 29 s. Similarly, SMS sent to mobile phone users to alert them of the extreme weather information was delivered to 99.6% of the intended users within a minute. 0.4% failure for the SMS possibly users are out of the coverage or mobile phone is off during evaluation. The time taken for the information to be delivered is conducive for the public to take necessary precautions to save lives and properties.

9 Conclusion

This study examined the current weather warning dissemination systems in the world and proposed a more feasible and cost-effective weather warning system to be utilized by developing countries, especially Tanzania. As mobile phone users increase every year, digital television broadcastings switch to portable smart devices. These advancements facilitate the transmission of critical information such as extreme weather alerts to many people in a short time. The TMA-CAP system can, therefore, be expanded to mobile and television broadcasting to reach a wider population, especially in developing countries than it is today. Thus, this study gathered and analyzed requirements for extending the CAP system, redesigned the prototype, and came up with an extended CAP architecture to be used for implementing extension features as well as evaluating the capability of the implemented prototype in disseminating the extreme weather.

Appendices

Appendix 1 Focus Group Discussion Questionnaire

1. Will you generally explain how the information broadcasting process is taking place?
2. Is the current broadcasting process (Equipment and Infrastructure) support interruption and allow other automatic broadcasting of sensitive information like the extreme weather warning? If yes, how does automatic broadcast happen? If No, will the TBC allow its implementation?
3. How possible is it that extreme weather warnings can automatically be sent to your devices and broadcasted to the public?
4. What are the best ways to send information and cover a larger population as possible by using electronic devices belonging to users?
5. Is there any upgrade plan for devices, specifications, and telecommunication infrastructure used in the entire context of the broadcasting process? If Yes, can you give us access/share with us the specification document?
6. What would be the best way to receive the extreme weather warning from TMA?
7. Will the automatic interruption of ongoing TV stations be allowed to allow broadcasting of the extreme weather warning?

Appendix 2 Figures for Prototype Implementation and Evaluation

```php
public function store(BroadcastsFormRequest $request)
{
    try {
                $data = $request->getData(); //Fetches information for broadcasting
                $file = $request->file('file_location'); //information location
                $name = time(). '-' .$file->getClientOriginalName(); //Capture time of publication
                $data['file_location'] = $name;

                $destinationPath = 'storage/broadcasts'; /*Directory where broadcasts
                                          is stored which is shared by broacasting station*/
                $file->move($destinationPath,$name); //Saving process

        Broadcast::create($data);
        return redirect()->route('admin.broadcast.index')
                          ->with('success_message', trans('broadcasts.model_was_added'));

    } catch (Exception $exception) {
        return back()->withInput()
                     ->withErrors(['unexpected_error' => trans('broadcasts.unexpected_error')]);
    }
}
```

Fig. 5 Information synchronization between TMA and TBC

```php
public function checkvideo(){

    $status  = Broadcast::where('flag', 1)->orderby('created_at','desc')->first()->exists();
    $video  = Broadcast::where('flag', 1)->orderby('created_at','desc')->first()->file_location;
    $updatingflag = Broadcast::where('flag', 1)->orderby('created_at','desc')->first();
    $updatingflag->update([
            'flag'=> 0
    ]);

    return response()->json([
        'message' => $status,
        'video' => $video,
    ],200);

}
```

Fig. 6 Interruption of an ongoing TV session

```php
public function store(Mobilereceivers $request)
{
    try {

        $data = $request->getData();
        //GET USER LISTS BY REGION/LOCATION  PASSED [illegible]RM THE FORM
         $userList = Contact::select('name','mobileno','id','location_id')->where('location_id','=',$request->location_id)->get();

      $this->send_sms_to_user($userList,$request->content);
         Mobilereceiver::create($data);

        return redirect()->route('admin.mobilereceiver.index')
                          ->with('success_message', trans('mobilereceivers.model_was_added'));

    } catch (Exception $exception) {

        return back()->withInput()
                     ->withErrors(['unexpected_error' => trans('mobilereceivers.unexpected_error')]);
    }
}
```

Registered mobile number receiver SMS
SMS Alerts
Selected contacts per location receives SMS alerts

Fig. 7 Received and stored extreme weather alerts

```php
public function send_sms_to_user($userList,$contents){
    //require('Msdgapisms.php');      // var_dump($userList); die();
    $msdg = new Msdgapisms();

    $datetime = date('Y-m-d H:i:s');

     $sms_content = $contents;
          $senderId = "tma" ;
     //recipient details as user_details
          foreach ($userList as $user) {
              //$recp = str_replace(' ', '', $user_details->phone);
        $recp = str_replace(' ', '', $user->mobileno);
        $recipients = ltrim($recp, '+');

              $operator = $this->getMobileOperator($recipients);

              /*$message  = array('message' => $sms_content,'datetime'=>$datetime, 'sender_id'=>15200,
              'mobile_service_id'=>371, 'recipients'=>$recipients,'mno' => $operator);*/

               $message  = array('message' => $sms_content,'datetime'=>$datetime, 'sender_id'=>$senderId,
                  mobile_service_id'=>134, 'recipients'=>$recipients);

              echo json_encode($message);

              $json_data = json_encode($message);

              $response = $msdg->sendQuickSms(array('data'=>$json_data,'datetime'=>$datetime));
              $logs = json_encode($response);


              $datas = json_decode($logs);

          $response = new Response();
          $response->location_id = $user->location_id;
          $response->contact_id = $user->id;
          $response->delivered_time = $datetime;
          $response->delivered_status = $datas->statusMessage;
          $response->created_at = $datetime;
          $response->updated_at = $datetime;
          $response->save();

              }

  }
```

Fig. 8 SMS sends engine

Tv Responses **(1)**

Broadcast Title	Start Synchronization	End Synchronization	Time Broadcasted	Station
	2020-03-09 19:20:06	2020-03-09 19:20:26	2020-03-09 19:20:35	TBC

Fig. 9 Warning alert to reach TV broadcasting station (TBC)

otal submited ((1000)) total failled ((4))

Contact	Location	Sending Time	Delivery Time	Time Taken	Delivery Stat
Name 1	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:27.271	0:0:1.271	Success
Name A	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:27.555	0:0:1.555	Success
Name 2	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:27.839	0:0:1.839	Success
Name B	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:27.1109	0:0:1.1109	Success
Name 3	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:28.1389	0:0:2.1389	Success
Name C	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:28.1663	0:0:2.1663	Success
Name 4	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:28.1737	0:0:2.1737	Invalid Inputs
Name D	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:28.2010	0:0:2.2010	Success
Name 5	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:29.2287	0:0:3.2287	Success
Name E	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:29.2562	0:0:3.2562	Success
Name 6	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:29.2846	0:0:3.2846	Success
Name F	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:29.3118	0:0:3.3118	Success
Name 7	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:30.3417	0:0:4.3417	Success
Name G	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:30.3691	0:0:4.3691	Success
Name 8	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:30.3967	0:0:4.3967	Success
Name H	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:31.4248	0:0:5.4248	Success
Name 10	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:31.4523	0:0:5.4523	Success
Name I	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:31.4834	0:0:5.4834	Success
Name 11	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:31.5111	0:0:5.5111	Success
Name J	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:32.5392	0:0:6.5392	Success
Name 12	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:32.5663	0:0:6.5663	Success
Name K	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:32.5954	0:0:6.5954	Success
Name 13	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:33.6232	0:0:7.6232	Success
	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:33.6506	0:0:7.6506	Success
Name 14	Kineto	2020-03-09 16:51:26	2020-03-09 16:51:33.6782	0:0:7.6782	Success

Fig. 10 Status of SMS sent to mobile phone users

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Socio-technical Cyber Resilience: A Systematic Review of Cyber Resilience Management Frameworks

Debora Irene Christine and Mamello Thinyane

Abstract Cybersecurity threats are regarded as one of the most significant global risks worldwide. The greater integration of technologies into organizational and societal functioning is associated with expanding cyber-attack surfaces and growing cybersecurity threats. Given the increasing frequency and complexity of adverse cyber events, organizations relying on digital technologies need to move from a posture of cybersecurity to one of cyber resilience to maintain their effective functioning. Cyber resilience management frameworks serve as the standard for organizations to build or improve their cyber resilience posture. Even though most cyber-attacks exploit the socio-technical gaps of a system, cyber resilience management frameworks proposed by security solutions providers, standard organizations, and academics have primarily employed a techno-centric approach to cyber resilience. This article explores the socio-technical shortcomings in cyber resilience management frameworks proposed in academic literature. To do so, it conceptualizes organizational cyber resilience from the perspectives of the socio-technical system. The systematic analysis contributes to identifying the extent of inclusion of socio-technical systems thinking in cyber resilience management frameworks and proposes potential future research directions.

Keywords Cyber resilience · Cybersecurity · Socio-technical · Framework · ICTs

1 Introduction

Technological risks associated with cybersecurity, including cyber-attacks, critical information infrastructure breakdown, and massive incidents of data fraud/theft, have constantly been listed as some of the most significant global risks in terms of impact and likelihood to organizations around the world in the World Economic Forum Global Risk reports from 2015 to 2021 (World Economic Forum, 2021). Not

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only government agencies and private companies that have become the targets of cybersecurity attacks, but also small- and medium-sized enterprises (SMEs), third-sector organizations (TSOs), and individual citizens, which notably are less prepared in terms of cybersecurity resources, and thus, more vulnerable to the adverse impact of cyber incidents. An organization's disrupted functioning due to an adverse cyber incident negatively impacts the organization's operations and stakeholders. Agrafiotis et al. (2018) identify five categories of organizational cyber harms: physical/digital harms (e.g., compromised information resources, bodily injury of personnel), economic harms (e.g., reduced profits, regulatory fines), psychological harms (e.g., personnel frustration and embarrassment), reputational harms (e.g., damaged public perception, loss of accreditations), and social/societal harms (e.g., negative changes in public perception, a drop in internal organizational morale).

A severe or prolonged impact of adverse cyber incidents on operations could also result in organizations going out of business due to expensive recovery or remediation (ITU & Symantec, 2015). This interrupts the sustained supply of products and services to the customers of businesses and the service users of public sector and third-sector organizations and undermines job creation, skills and technology development, innovation, and the distribution of wealth, thereby impeding sustained socio-economic and cultural development, making cybersecurity an essential sustainable socio-economic development factor (Vasiu & Vasiu, 2018).

Today, the greater integration of technologies into organizational and societal functioning is associated with expanding cyber-attack surfaces and growing cybersecurity threats. This cyber threat landscape requires organizations across sectors to shift from a cybersecurity mindset, which focuses on avoidance of and protection from adverse cyber events, or cyber risk mitigation, and the development of fail-safe systems, to cyber resilience, which entails anticipation and adaptation for continuity and the development of systems that are safe-to-fail (Björck et al., 2015). A resilient cyber posture allows organizations to maintain the most critical assets and services available while isolating disruptions, minimizing damage and recovery time, and improving the system's resilience.

Cyber resilience has been increasingly adopted as a conceptual framework to deal with the growing risk of crisis and disruptions in cyber systems and cyber-enabled systems, especially in relation to cyber-attacks. A variety of cyber resilience frameworks have been proposed for application in a variety of cyber-supported systems, including transportation networks (Renne et al., 2020), smart cities (AlDairi & Tawalbeh, 2017), smart grids (Bhardwaj et al., 2016), and critical infrastructure (Cadete et al., 2018).

While there are many approaches and frameworks for strengthening the cybersecurity, information security, and cyber resilience posture of organizations, they have primarily been focused on strengthening technical controls and countermeasures and neglected the organizational aspects that are more focused on people and processes (Laybats & Tredinnick, 2016). As a result, cyber threats which compromise human cognitive biases and their lack of cybersecurity awareness and skills, such as social engineering and insider threats, have largely been left unaddressed through organizational practices (Budzak, 2016; Soomro et al., 2016). Further, the insights that inform the development of these frameworks have mainly been the risk landscape and operations continuity requirements of organizations in the private and public sectors, making them less relevant to be adopted by organizations in other sectors.

Addressing the cyber vulnerabilities at the intersections of an organization's social, technical, and environmental dimensions requires organizations to build and maintain socio-technical cyber resilience. In this regard, socio-technical systems (STS) theory provides the basis to recognize organizations as STS and cyber resilience as a socio-technical capability engineered in organizations. Further, STS provides a lens to understand the connection between cyber resilience and the subsystems of sustainability.

The article seeks to identify the extant development of cyber resilience management (CRM) frameworks for organizations proposed in academic literature. While by no means purporting to offer an exhaustive overview of CRM frameworks, we hope to highlight the socio-technical gaps in the frameworks and contribute to the scholarship in resilience engineering for STS and organizational management while furthering the discussion on the socio-technical dimensions of cyber resilience.

This article proceeds as follows. Sect. 2 discusses the STS theory, the framing of organizations and cyber resilience as socio-technical, and related works in cyber resilience management. Sect. 3 presents the systematic literature review method employed in the research. Sect. 4 presents an analysis of the sample. We conclude the paper with a summary and direction for further developments necessary for cyber resilience.

2 Organizational Socio-technical Cyber Resilience

2.1 Organization as a Socio-technical System

The STS theory is an approach to studying the interrelatedness of social and technical dimensions of a system while considering the operating environments in which the system is embedded (Appelbaum, 1997; Walker et al., 2004). An STS consists of three dimensions: social, technical, and environmental (Bostrom & Heinen, 1977; Davis et al., 2014). As opposed to simply being aggregations of people and technology, an STS is intentionally hybrid (Kroes et al., 2006; Vermaas et al., 2011). It represents a purposeful structure of interrelated and interdependent social and technical factors, directly or indirectly affecting each other, to maintain their operations and the system itself to pursue its goal (Walker, 2015).

Organizations can be understood as an STS (Davis et al., 2014) comprising humans who apply solutions, including technological ones, to execute work activities through organizational processes and social structure to accomplish organizational goals within a complex operating environment (Bella et al., 2015; Carayon et al., 2015). The social dimension comprises an organizational structure (e.g., values, norms, coordination needs) and actors (i.e., stakeholders influencing or performing work activities). The technical dimension comprises technology (e.g., technological resources, procedures) and work activities (e.g., activities carried out within social infrastructures). The environmental dimension refers to the factors influencing and impacting the organization. It includes social, political, economic, technological, environmental, and legal factors (Schuetz & Schrefl, 2017). Given increasing digitalization, automation of work processes, and interconnectedness of cyber technical artifacts into organizations' functioning, this article extends the concept of STS to include computational artifacts used in an organizational setting. It considers the symbiotic interactions between these artifacts with other components of an organization's STS.

The objective of STS theory is to close the misalignments between the social, technical, and environmental domains, called socio-technical gaps, through a process called "joint optimization" (Whitworth, 2009). An organization can perform optimally only if these interdependent domains or subsystems are designed to fit the demands of each other—humans are committed to their tasks while technology is operated to its full potential. This approach is particularly relevant today as cybersecurity threats have increasingly compromised not only the technical shortcomings of an organization's cyber posture, but also human cognitive and behavioral factors (Carlton et al., 2019). Corollary to that, introducing computational artifacts into an organization's activity must be pursued along with appropriate capacity building of personnel on how to use the technology to execute work activity and possibly structural changes. Socio-technical such as personnel's lack of awareness of their cybersecurity responsibilities could result in critical system failures and data breaches despite flawless system engineering and institutionalization of cyber resilience policies and procedures.

2.2 Cyber Resilience as a Socio-technical Capability

Resilience was first introduced by Holling (1973) to characterize the capacity of socio-ecological systems to recover from a long-term crisis. Currently, resilience is used in many fields, including individual and organizational psychology, strategic management, urban studies, and resilience engineering. It represents the ability to adapt to a changing environment and survive flexibly despite facing difficulties and recovering from a destabilizing perturbation in the work as it attempts to reach its primary goals. It has also been referred to as the ability for risk-aversion and crisis control at every level of society, from individuals to entities.

Socio-technical resilience scholars argue that since STS are hybrid entities in which the social and technical are completely fused and inseparable and co-produce and co-constitute (Amir, 2018), resilience should be understood as a feature that is produced by a hybrid construct where humans are blended with the materiality of technology. This article discusses resilience from the perspectives of the organizational management of the STS in which technical, human, and organizational factors interact with each other's emerging complicated behaviors. The interactions between these factors are designed to produce the correct functioning of the system. A breakdown or failure in this intentionally created correct functioning may lead to accidents, including adverse cyber events. It would require socio-technical transformation involving structural or relational changes to cope with the suddenly altered environment (Amir & Kant, 2018). This socio-technical transformation should be understood as an intentional modification (repair or adapt) that takes place in an organized fashion (Amir & Kant, 2018).

Cyber resilience, the capacity of a system to recover from the consequences of an adverse cyber event and "continuously deliver the intended outcome despite adverse cyber events" (Björck et al., 2015: 2) has been identified as a desirable system capability (Khan & Estay, 2015). Cyber resilience involves the process of planning for, absorbing, recovering from, and adapting to adverse events (Linkov & Kott, 2019). Building an organization's cyber resilience requires comprehension of all dimensions forming its context and shaping its transformability in times of crisis. Accordingly, organizational practices, from anticipatory to adaptation intended to maintain cyber resilience, need to address the vulnerabilities emerging from the said dimensions and misalignment between the socio-technical dimensions while considering the operating environment within which they interact. In that respect, cyber resilience can be understood as a socio-technical capability.

2.3 Cyber Resilience and Sustainability

The STS theory places an equal emphasis on the social, technical, and environmental factors affecting security and resilience practices. An STS is regarded to be susceptible to environmental factors cutting across the social and technical dimensions. Relatedly, cyber resilience considers a wide range of cyber threats, including those associated with environmental conditions, which can affect cyberinfrastructure. There is also growing literature proposing the connection between global environmental governance with cybersecurity and cyber resilience (see, for example, (Cassotta & Sidortsov, 2019).

Adverse cyber events such as climate change-induced frequent power grid failure suggest the importance of environmental sustainability for cyber resilience. On the other hand, increasing cyber-attacks on critical infrastructures disrupting the provision of public services to civilians implies the significance of societal cyber resilience for ensuring socio-economic sustainability. This societal cyber resilience can only be achieved through collaboration between societal stakeholders, including individuals, groups, organizations, and institutions. Accordingly, organizations across the public, private, and third sectors need to be cyber resilient to carry on their contribution to sustainable development through the provision of goods and services, job creation, transfer of knowledge and skills, innovation development, distribution of wealth, and advocacy for justice.

2.4 Related Work

Cyber resilience management is often built according to existing frameworks, standards, and/or best practices. ISO/IEC 27002, COBIT 5 for Information Security, the National Institute of Standards and Technology's cybersecurity framework (NIST-CF), and the IT capability maturity framework (IT-CMF) are among the widely known and most used frameworks and standards. ISO/IEC 27002 is a compliance framework that defines basic requirements for the implementation of an information security management system. Meanwhile, COBIT 5 (ISACA, 2012) is regarded as a governance framework (Nicho, 2018). The NIST-CF (NIST, 2018) and IT-CMF (Curley et al., 2017) can be considered as a combination of compliance and governance frameworks, thereby management frameworks, due to their focus on the effective integration of IT to organizational goals.

Despite the scope of organizational practices covered in the frameworks, a techno-centric approach to cybersecurity, information security, and cyber resilience is prevalent (Tisdale, 2015). Other shortcomings highlighted in the literature include the generic scope of the standards (Siponen & Willison, 2009), which leads to inefficient or even misleading risk mitigation strategies (Fenz et al., 2013), the complexity of practical implementation (Mijnhardt et al., 2016), the lack of implementation guideline, and the lack of the universal relevance of the frameworks.

There already have been attempts to review the extant CRM frameworks. Sepuvelda Estay et al. (2020) identify the research gaps, similarities, and synergies between CRFs and map them into the Wave Analogy (Guerra & Sepulveda Estay, 2019). It finds that most of the frameworks have been focused more on the operational aspects of cyber resilience and less on the governance and the management of social capital. This confirms the unbalanced emphasis on the social and technical dimensions of STS cyber resilience. The work of Malatji et al. (2019) applies an STS theory to analyze the socio-technical gaps in authoritative enterprise systems security frameworks developed by information security firms and institutions. Annarelli et al. (2020) explore how CRM frameworks consider organizational contextual factors, such as infrastructure, industry, and ownership in the management of cyber resilience systems.

Despite existing reviews of the CRM frameworks, there is a lack of studies that acknowledge the significance of optimizing the technical and non-technical measures of the frameworks. While by no means purporting to offer an exhaustive overview of CRM frameworks, this article seeks to complement limited studies on the socio-technical dimensions of cyber resilience and cyber-resilient organizations by reviewing organizational CRM frameworks discussed in academic literature to identify their socio-technical shortcomings.

3 Methods

In our data collection quest, we are interested in how cyber resilience is operationalized in the CRM frameworks, which dimensions of socio-technical cyber resilience and phases of cyber resilience management are considered; the types of cybersecurity threats that are considered and addressed; the types of organization that the framework is developed for; and the gap that motivates the development of the framework. These queries inform the development of the thematic codes used in the analysis of the included studies.

3.1 Document Selection

From October 2020 to January 2021, a systematic literature review of two Scopus and ScienceDirect was performed. The searched terms are combined using Boolean logic:

cyber AND (resilien* OR security) AND (management OR assessment OR response OR recovery OR evaluation) AND (model OR method OR framework OR standard OR metric)

The inclusion criteria are (1) papers published as articles in peer-reviewed journals or conference proceedings, (2) written in English, and (3) Open Access.

The search protocol from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Moher et al., 2009) is followed and results in 688 papers (Fig. 1). The results are scanned for duplicates (85), and 603 remain. In the next phases, Protocol 1 and Protocol 2 are applied to ensure only relevant articles are considered.

Protocol 1 aims to ensure that only articles discussing the cyber resilience framework for strengthening cyber resilience at a narrow scope within the internal organizational setting are included. It is applied to screen the title and abstract of the remaining 603 articles. Articles that focus mainly on national resilience, community resilience, and human resilience as the referent security object in relation to the cyber system are excluded, together with those that merely focused on the technical resilience of a cyber system or specific assets, such as networks, devices, applications, or data. This results in 135 articles being excluded.

Next, Protocol 2 is applied to review the remaining 468 articles in full text. Protocol 2 aims to identify if the filtered papers outline coordinated activities to direct and control an organization regarding its cyber resilience. A total of 453 articles are excluded for only (1) identifying characteristics or architecture of a cyber-resilient system, (2) modeling cyber threat and cyber-attack kill chains, (3) modeling the structured reasoning of the decision-making process for dealing with cyber threats, (4) predicting the impact of an adverse cyber event, (5) outlining strike back capabilities against cyber-attacks (retaliation/defense modeling), and

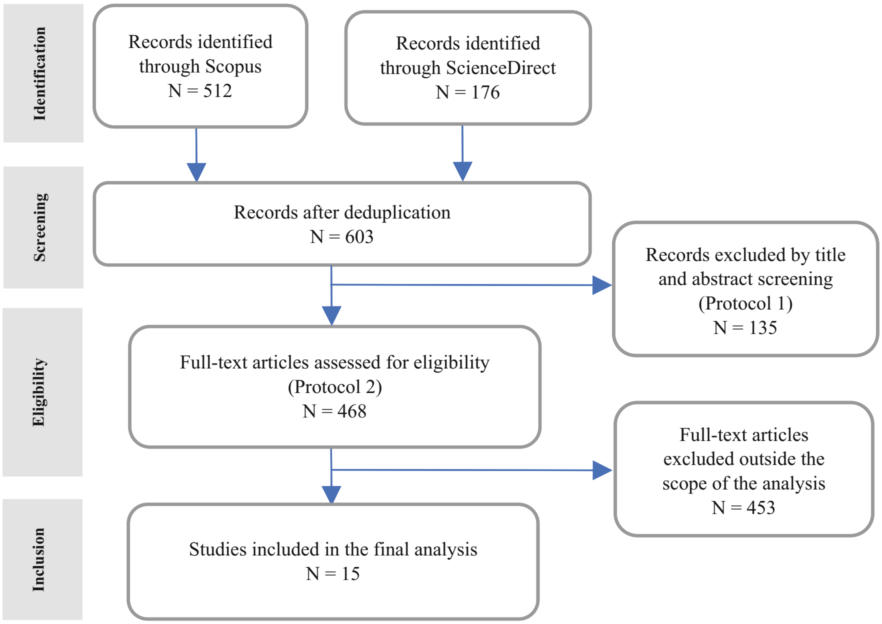

Fig. 1 Literature search strategy

(6) providing cyber risk assessment methods. In the end, 15 articles are included in the final sample.

3.2 Literature Analysis/Coding

We employ a two-cycle coding technique for the thematic analysis part of this research. Phase 1 (open coding) begins with reading through the transcribed text to locate the organizational practices and cyber resilience management cycle. The process of open coding refers to a non-hierarchical deconstruction of data. In this phase, the texts are coded as is.

In Phase 2, the process of categorization takes place. The codes from Phase 1 are categorized into clusters based on their similarities. Concepts are gathered and grouped according to the pattern that emerges in each literature. For example, in terms of cyber resilience countermeasure and control, "access to systems and assets is controlled, incorporating the principle of least functionality" (Benz & Chatterjee, 2020), "multi-factor authentication" (Bouwens & Stafford, 2019), and "access control and cryptography" (Cadete et al., 2018) are all related to establishing and managing user's access to critical assets. Thus, they are grouped under Access management domain practice. Later, each is assigned a specific sub-domain practice.

In terms of the socio-technical capability domain, the first practice is under Organizational structure while the other two are under Technology.

4 Analysis

4.1 Descriptive Analysis

Differences can be detected in every cyber resilience framework, which depends on the context of the framework development. This part focuses on elaborating these different contexts through descriptive coding outcomes: the development objective, literature gap, target user, development method, and cyber threat (Table 1).

4.1.1 The Research Gaps

Several gaps and shortcomings in existing CRM frameworks are identified in the articles under review. These gaps refer to unexplored or underexplored topics or approaches in the CRM literature. The gaps, as outlined in Table 1 include the gap in the conceptual approach to CRM (e.g., regarding human factors, managerial point of view), the gap in the contextualization of CRM frameworks (e.g., HEIs, SMEs, MNCs, cloud computing users), the gap in threat-based approach to CRM (e.g., APT, crypto-ransomware, cloud incidents), complex best practice recommendations, the lack of comprehensive frameworks, and the lack of implementation guidance of the framework. The second category is identified the most in the papers under review, emphasizing the importance of considering the contextual needs of organizations for the selection and implementation of CRM frameworks.

Aliyu et al. (2020) propose a cybersecurity maturity assessment framework that incorporates security regulations, privacy regulations, and best practices that HEIs must be compliant with. The framework enables self-assessment and audit, thus, facilitating HEIs to perform a gap analysis in their cybersecurity readiness and compliance and to strengthen the level of cybersecurity.

Annarelli et al. (2020) identify three recurring contextual factors in the literature which are important in determining managerial cyber resilience practices to undertake. These are infrastructure (i.e., the assets that are essential for maintaining vital organization's functions), industry (i.e., the sector in which the organization is embedded), and ownership (i.e., the ownership structure of the organization).

Bernik and Prislan (2016) consider existing information security models, standards, and recommendations are excessively complex and demanding, thus are difficult to execute for organizations lacking financial resources and expertise. They outline a multidimensional information security performance model intended as a practical tool for different organizations to assess their information security performance and improve planning. The model considers that technological, organizational, and environmental contexts presuppose an organization's technological

Table 1 Context of the cyber resilience frameworks

Author, year	Objective	Gap addressed	Target user	Method	Cybersecurity threat
Aliyu et al. (2020)	Proposing a cybersecurity assessment tool for higher education institutes (HEIs)	The lack of holistic cybersecurity models tailored for HEIs	Sector-specific–HEIs	Model optimization	Not specified
Annarelli et al. (2020)	Proposing a cyber resilience management framework focusing on the managerial roles	The lack of cyber resilience management frameworks that consider contextual factors of organizations	Private	Literature review; case study	Not specified
Benz and Chatterjee (2020)	Proposing a cyber resilience evaluation framework for SMEs	The lack of practical cyber resilience management frameworks that meet the needs of SMEs	Private–SMEs	Model optimization; sector-specific requirements evaluation; survey	Not specified
Bernik and Prislan (2016)	Proposing an information security performance measurement model for internal system evaluations and decision-making	Existing information security metrics are underdeveloped and too complex.	Not specified–organizations in general	Literature review; expert validation	Information threats
Bouwens and Stafford (2019)	Mapping resilience characteristics across systems and organizations	The lack of literature on organizational cyber resilience capabilities	Not specified–organizations in general	Qualitative synthesis	Advanced persistent threats (APTs)
Cadete et al. (2018)	Proposing a cyber resilience management framework	The lack of guidance to implement conceptual process-based cyber resilience management models	Sector-specific–critical infrastructures (CIs)	Case study	Not specified
Connolly and Wall (2019)	Presenting a taxonomy of countermeasures against crypto-ransomware	The need for a multi-layered approach to building organizational cyber resilience against crypto-ransomware	Not specified–organizations in general	Text analysis for taxonomy development	Crypto-ransomware
DiMase et al. (2015)	Proposing an integrated cyber-physical systems (CPS) security framework	The need for a risk management framework that includes all security domains to ensure resilience	Sector-specific–CPS	Hierarchical modeling	Not specified

Herrera and Janczewski (2016)	Proposing a conceptual framework for cyber resilience management	The need for an organizational cyber resilience framework for organizations relying on cloud computing	ICT use-specific–cloud computing	Text analysis; interview and tabletop exercise for validation	Cloud incidents
Lees et al. (2018)	Proposing a cyber resilience management framework for multinational corporations (MNCs)	Existing cyber resilience frameworks for multinational corporations are inadequate.	Private–MNCs	Text analysis	Not specified
Linkov et al. (2013)	Proposing a cyber resilience management framework	The need for a cyber resilience framework that considers the interactions between the different organization's domains across all resilience management phases	Not specified–organizations in general	Text analysis	Not specified
Ramezani and Camarinha-Matos (2019)	Proposing a framework that operationalizes an approach to build a cyber-resilient business ecosystem	The need for a cyber resilience framework that supports collaborative business ecosystems	Private	Text analysis; modeling	Not specified
Rehak et al. (2019)	Proposing a methodology for cyber resilience assessment	The need for a procedure for dynamic evaluation of critical infrastructure sectors	Sector-specific–CI	Framework review	Natural, process-technological threats
Spruit and Roeling (2014)	Proposing a framework to improve information security maturity within an organization and ensure business continuity after an attack	The lack of information security and resiliency frameworks that meet the needs of SMEs	Private–SMEs	Framework review; expert interview for validation	Not specified
Tapia et al. (2020)	Proposing a framework for system resilience management	The lack of cyber resilience management frameworks which fit the complex environment of cyber-physical power systems (CPPS)	Sector-specific–CPPS	Interview and workshop for requirements assessment; modeling	Failures of CPPS due to technical or human factors

development. The need for a practical cyber resilience management framework for smaller organizations with limited resources and expertise is also observed by Benz and Chatterjee (2020) and Spruit and Roeling (2014) who propose frameworks for SMEs.

The myriad of cybersecurity incidents that could result in intrusions on an organization's network demands cyber resilience management frameworks to consider all relevant vulnerabilities and exploits, and thus threat models or kill chains of different cybersecurity threats. Bouwens and Stafford (2019) propose a cyber resilience management framework that provides strategies for addressing APTs. Connolly and Wall (2019) develop a data-driven taxonomy of crypto-ransomware countermeasures. Herrera and Janczewski (2016) suggest a framework for cloud supply chain resilience coordination.

Cadete et al. (2018) observe the lack of specific guidance for implementing conceptual models of CI cyber resilience management which would enable assessment and audit of CI's cyber resilience consistently. Relatedly, Rehak et al. (2019) argue that managing CI's cyber resilience demands a complex approach to assessing the robustness, recoverability, and adaptability of CI elements in response to disruptive events of naturogenic, technogenic, and anthropogenic origin. The lack of a comprehensive approach to CI's cyber resilience leads them to design the Critical Infrastructure Elements Resilience Assessment (CIERA) framework.

DiMase et al. (2015) and Tapia et al. (2020) find that the complex environment of CPS demands that all vulnerabilities in CPS are considered in the development of a cyber resilience management framework. DiMase et al. (2015) propose a framework that includes ten areas of concern for CPS and crosscutting capabilities necessary to fully address CPS security. Tapia et al. (2020) present a CPS resilience management framework that considers elements across the domains of technology, people, organizational policies and procedures, and regulations.

Lees et al. (2018) consider that MNCs face different legal and regulatory landscapes compared to other organizations, resulting in different challenges for cybersecurity and cyber resilience. Based on such assessment, they propose a cyber resilience management framework that considers factors such as the size of operations of MNCs, their level of automation, level of supply chain integration, and level of connectivity.

Linkov et al. (2013) observe that existing cyber resilience approaches have overlooked the interaction between all aspects of an organization across each stage of the cybersecurity incident management cycle. Combining the Network-Centric Warfare's (NCW) four operational domains (physical, information, cognitive, social) and the National Academy of Sciences (NAS) four systems functions (plan/prepare, absorb, recover, adapt), they propose effective resilience metrics for cyber systems.

Ramezani and Camarinha-Matos (2019) argue that collaboration in business ecosystems is crucial for dealing with disruptions as it provides shared competencies and assets. They propose a framework that supports organizations in leveraging multiple forms of collaborative networks toward the management of cyber resilience and considers collaboration-related issues, such as vertical integration of smart production systems and horizontal integration through global value chain networks.

4.1.2 The Target User

The target users are categorized as private-sector organizations, sector-specific organizations, ICT use-specific organizations, academia, and organizations in general (i.e., those not specifying the intended user of the framework). Both private-sector organizations and sector-specific organizations are the most identified as intended users, while there is only one CRM framework that is targeted at organizations using cloud computing. Several papers do not identify the specified target user of the framework, thereby having general applicability for organizations.

A gap emerging from the literature that needs addressing is the absence of CRM frameworks specifically designed for the public sector and third-sector organizations (TSOs). TSOs notably have far less awareness, resources, and capacity for strategic cyber resilience planning (Jagalur et al., 2018). While well-established frameworks, such as the NIST-CF and COBIT 5 for information security, might be applicable for public-sector organizations, the cybersecurity and cyber resilience needs of TSOs are significantly different from those of the private- and public-sector organizations.

4.1.3 The Method to Develop the Framework

The methods used in developing and validating the proposed CRM frameworks are case study, literature review, framework review, model optimization, sector-specific requirements evaluation, qualitative synthesis, modeling, text analysis, interview, and workshop.

4.1.4 The Cybersecurity Threats

While the cybersecurity threats identified in the frameworks emerge from the intersections of the STS dimensions, in general, they can be categorized into environmental (e.g., natural disaster), social (e.g., information threat), and technical (e.g., cloud incident, APT, crypto-ransomware).

4.2 Thematic Analysis

The thematic analysis categorizes the articles in the synthesis sample according to the operationalization of cyber resilience into organizational practices.

4.2.1 Cyber Resilience Organizational Practices

Table 2 shows the grouping of organizational practices shared by CRM frameworks in the reviewed literature and their definition. We find 589 organizational practices that we group into 42 sub-domain practices based on their overlapping functionality regarding their contribution to the domain practices. Subsequently, we identified the STS capability domain of each organizational practice. The domain practices in Table 2 are adapted from common cyber resilience domains found in existing CRM frameworks, namely NIST (2018), COBIT 5 (ISACA, 2012), the Cybersecurity Emergency Response Team Resilience Management Model (CERT-RMM) (Caralli et al., 2016), and Information Security Management Maturity Model (O-ISM3) (The Open Group, 2017).

Table 3 shows how the frameworks under review compare to each other based on their socio-technical capability domains. As shown in the table, only 2 out of 15 frameworks completely fulfill the requirements of an STS. The other frameworks only partially fulfill the requirements. Therefore, there is a discernible socio-technical gap in the frameworks that only partially fulfill the STS requirements.

All the frameworks include at least one organizational practice which falls under Organizational structure, Technology, and Work activity. Among the capability domains, Actor is the least included, followed by attributes of the environmental dimension. In the analyzed frameworks, this gap exists because of the emphasis on the Technical dimension over the Social dimension. When the social and technical dimensions are targeted separately, important dynamics of the STS as a totality may be misunderstood or lost. The gap creates an exploitable vulnerability through which adverse cyber events could compromise the STS via the less emphasized dimension. The findings from this review align with the trends in CRM frameworks which emphasize engineering and other technical skills while understating the importance of social and organizational factors in daily occurrences.

While almost all the frameworks do not specifically identify roles associated with cybersecurity and cyber resilience function, some include organizational practices corresponding to the capability domain Actor. Rehak et al. (2019) identify the need for a "CSIRT/security team in an organization" and Bernik and Prislan (2016) identify "formal authority of security personnel—the ability of decision-making," qualified staff, and the need for professional training of security and technical personnel. Connolly and Wall (2019) include "IT expertise" and the need for "cybersecurity champions." Benz and Chatterjee (2020) include the establishment of "cybersecurity roles and responsibilities (e.g., employees, subcontractors, clients, partners)" in the framework. Linkov et al. (2013) include "experts and resilience-responsible personnel." Bouwens and Stafford (2019) include "a trained team with the right tools" as an enabler of a quick intrusion detection process.

None of the frameworks that leave out the capability domain Actor includes establishing security roles and responsibilities or cybersecurity governance, which may indirectly refer to the role of people toward attaining an organization's cybersecurity and cyber resilience. This means that these frameworks do not specifically

Table 2 Grouping of cyber resilience controls and countermeasures into domains

Domain practices	Sub-domain practices	Definition
Asset management	Asset inventory	Identification and active documentation of assets
	Asset management	Management of identified assets during their life cycle to ensure sustained productivity to support critical services
Knowledge and information management	Information classification	Classification of all information assets depending on their criticality, confidentiality, and business value
	Information resources management	Management of the security of information resources to ensure their confidentiality, integrity, and availability
	Knowledge management	Management of the security of the organization's knowledge resources to ensure their confidentiality, integrity, and availability
Technology management	Security technologies	Use of security technologies to protect assets
	Network and device management	Establishment, implementation, and active management of network infrastructures and devices
Physical security		Establishment, implementation, and active management of facilities' physical security
Personnel security		Management of the proper authentication and authorization level controlling personnel and/or visitors' access in the physical facilities of the organization
Access management	Access control management	The processes and tools used to track, control, prevent, and correct secure access to critical assets according to the formal determination of which persons, computers, and applications have a need and right to access these critical assets based on an approved classification
	Change and configuration management	Processes and procedures to ensure the integrity of assets using change control and change control audits
Vulnerability management	Vulnerability identification and analysis	Continuous acquisition and elaboration of information to identify vulnerabilities in the organization's operating environment
	Vulnerability management	Continuous remediation and minimization of identified vulnerabilities
Awareness and competency	Awareness and education	Awareness-raising activities conducted to enhance personnel cognition regarding their roles and responsibilities in organization's cyber resilience management and internal policies and procedures and to promote security-conscious behavior
	Skills training	Training activities for personnel aimed to improve their capacity to perform their cybersecurity-related duties and

(continued)

Table 2 (continued)

Domain practices	Sub-domain practices	Definition
		responsibilities consistent with related policies, procedures, and agreements
Risk management	Risk assessment	Identification of organizational vulnerabilities repeated at regular intervals or when significant changes occur
	Risk management strategy	Establishment of the organization's priorities, constraints, risk tolerances, and assumptions to support operational risk decisions
	Risk management	Implementation of risk management strategy
External environment connections	External dependencies management	Establishment and active management of the external environment connections of the organization
	Collaboration and cooperation	Collaborative activities with external stakeholders
Resilience governance	Policies and procedures establishment	Establishment, implementation, and active management of internal policies and procedures
	Policies and procedures enforcement	Enforcement of established policies and procedures
	Compliance with legal and contractual requirements	Adherence of internal policies and procedures to the organization's legal and contractual requirements
	Resilience requirements identification	Identification, documentation, and analysis of operational resilience requirements of critical services and related assets
	Resilience requirements development	Development, establishment, or engineering of resilience requirements solutions of critical services and related assets
	Resilience requirements management	Management of resilience requirements of critical services and related assets and addressing inconsistencies between the requirements and current organizational practices
	Security roles and responsibilities	Identification and clear segregation of security roles and responsibilities
Supporting resilience	Resilience funding	Ensuring sustainable funding of organizational resilience practices
	Resilience-supporting communications	Collecting data and facts related to cyber incidents.
	Human resources management	Protection of the organization's information, as well as its reputation, by developing and implementing an incident response infrastructure
	Alignment with business objectives	Establishing roles and functions which are responsible for leading the design and implementation of cybersecurity and cyber

(continued)

Table 2 (continued)

Domain practices	Sub-domain practices	Definition
		resilience-related practices and processes in the organization
	Improvement	Efforts to improve the overall organizational practices and processes
Situational awareness	Continuous monitoring	Continual checking and critical observation or determining the status to identify change from the performance level required or expected
	Detection and analysis	Development and implementation of appropriate activities to identify the occurrence of a cybersecurity event
Crisis preparedness	Incident and continuity planning	Establishment of plans and procedures for incident response and management to ensure operational continuity and recovery
	Internal reporting	Establishment of mechanisms for consistent reporting of incidents
	Exercises and simulations	Simulations designed to test and validate established emergency plans
	Incident management	Implementation of incident response plan and procedures in the face of cyber events
Learning and improvement	Documentation and post-incident knowledge management	Active documentation of event logs in an incident knowledgebase
	Incident analysis	Analysis of documented cyber event logs to determine the source, motive, and impact of an event on assets and operations and identify vulnerabilities
	Post-incident resilience posture review	Review of asset and service configurations and evaluation of incident preparedness following a cyber event to determine effectiveness and improvement for better crisis preparedness
	Post-incident corrective actions	Transformation of organizational practices by incorporating lessons learned from a cyber event into future activities while addressing resilience requirements

suggest the need for establishing roles or structures for the suggested Work activity. If cyber resilience roles and responsibilities for the entire workforce and third-party stakeholders are not established, they will not be able to perform those activities optimally. Further, even with a systems security that safeguards against adverse cyber events and standardized processes and procedures, an organization would still need authorized personnel who are responsible for implementing the formalized socio-technical management process and monitoring the STS optimization practices. COBIT 5, for example, recognizes the need for establishing an organizational structure with the following roles: chief information security officer, information

Table 3 Comparison between frameworks

Author	Social dimension		Technical dimension		Environmental dimension
	Organizational structure	Actor	Technology	Work activity	
Aliyu et al. (2020)	●		●	●	●
Annarelli et al. (2020)	●		●	●	
Benz and Chatterjee (2020)	●	●	●	●	
Bernik and Prislan (2016)	●	●	●	●	●
Bouwens and Stafford (2019)	●	●	●	●	
Cadete et al. (2018)	●		●	●	●
Connolly and Wall (2019)	●	●	●	●	
DiMase et al. (2015)	●		●	●	●
Herrera and Janczewski (2016)	●		●	●	
Lees et al. (2018)	●		●	●	●
Linkov et al. (2013)	●	●	●	●	
Ramezani and Camarinha-Matos (2019)	●		●	●	●
Rehak et al. (2019)	●	●	●	●	●
Spruit and Roeling (2014)	●		●	●	●
Tapia et al. (2020)	●		●	●	●

security steering committee, information security manager, and enterprise risk management committee (ISACA, 2012).

Further, the exclusion of attributes related to the Environmental dimension suggests that factors external to the organization with a direct or indirect impact upon it are considered not important or irrelevant for the management of cyber resilience. This can lead to the lack or absence of resilience planning to deal with adverse cyber events exploiting the organization's vulnerabilities related to these environmental attributes, including compliance requirements to national and international standards, external dependencies, and socio-political turbulence. The socio-technical gap identified in the CRM framework may result in a socio-technical gap in the organization's cyber resilience posture where the framework is implemented.

4.2.2 Cyber Resilience Management Phases

The mapping exercise in Table 3 provides an overview of the socio-technical gaps in CRM frameworks proposed in the literature. Assessment of the adherence of the frameworks to the cyber resilience concept could also be conducted through mapping the organizational practices included in the framework against phases of cyber resilience management.

In general, cyber resilience management is divided into four phases: *plan for/prepare, absorb, recover from,* and *adapt to* adverse events (Linkov & Kott, 2019). The *prepare* phase starts before the onset of adverse cyber incidents, where efforts to anticipate, monitor, prevent, and mitigate the incidents take place. The *absorb* phase is triggered by the occurrence of an adverse cyber event, which reduces the system's capacity to function optimally. The effectiveness of the *absorb* measures adopted in this phase determines the extent and severity of the impact of the adverse incident.

The *recover* phase starts the moment the adverse incident stops or is halted and when restoration of lost cyber functioning begins. Timely and effective recovery actions are necessary to reduce the compounded negative impacts of disrupted cyber functioning. Once baseline cyber functioning has been restored, the *adapt* phase can commence to inform the evolution and increase in cyber functioning.

Among the four phases in which a resilience management process is conventionally divided, the frameworks assign more countermeasures in the *plan* and *absorb* phases, while some frameworks do not include either the *recover* or the *adapt* phase. The preparation and maintenance of countermeasures outlined in Table 3 occur in the *plan* phase, while the deployment of the defensive countermeasures takes place in the *absorb* phase. In the *recover* phase, the recovery plan is executed, adverse events are logged (sub-domain Documentation and post-incident knowledge management), and the confidentiality, integrity, and availability of access are restored (Asset management). In the *adapt* phase, activities to improve the performance of assets, practices, and processes that contribute to an organization's cyber resilience are executed (sub-domain Post-incident resilience posture review and Post-incident corrective actions). Timely and effective recovery actions are necessary to reduce the compounded negative impacts of disrupted cyber functioning. Once baseline functioning is restored, the *adapt* phase can commence.

As demonstrated in Table 4, nine frameworks under review are developed according to the CRM cycle. However, three out of the frameworks that include the cycle do not include the *adapt* phase. Indeed, the three frameworks do not suggest any organizational practices which would enable institutional reconfigurations to adapt to post-crisis environments. A cyber-resilient system emphasizes the fault-tolerant, recoverability, transformability, and adaptability aspects of a system. The exclusion of the *adapt* phase from the CRM cycle indicates a lack of attention given to the utilization of knowledge and experience gained from an adverse cyber event to become more resilient in the future.

Table 4 Cyber resilience management phases in the frameworks

Author, year/Phase	Plan	Absorb	Recover	Adapt
Aliyu et al. (2020)	Identify	Protect, detect	Respond, recover	
Annarelli et al. (2020)	Plan, prepare	Absorb	Recover	Adapt
Benz and Chatterjee (2020)	Identify, detect	Protect	Respond	
Bernik and Prislan (2016)	N/A			
Bouwens and Stafford (2019)	Expect, anticipate, monitor	Detect, report, learn, interpret, contain, protect, resist, absorb	Eliminate, recover	Adapt, learning
Cadete et al. (2018)	Identify, detect	Protect, respond	Recover	
Connolly and Wall (2019)	N/A			
DiMase et al. (2015)	Plan/prepare	Absorb	Recover	Adapt
Herrera and Janczewski (2016)	Protect	Respond		Adapt
Lees et al. (2018)	N/A			
Linkov et al. (2013)	Plan/prepare	Absorb	Recover	Adapt
Ramezani and Camarinha-Matos (2019)	N/A			
Rehak et al. (2019)	Prevent	Absorb	Recover	Adapt
Spruit and Roeling (2014)	N/A			
Tapia et al. (2020)	Prepare, prevent	Implement robust and precautionary design	Manage and recover from crisis	Learn for the future

5 Discussion and Conclusion

5.1 Discussion

The literature review found that despite significant development in CRM frameworks in the past decades, the everchanging cyber threat landscape and cyber resilience needs of organizations render further development and contextualization of CRM frameworks imperative. Different approaches to developing CRM frameworks are used in the literature to address the specific needs of intended users. Most of the frameworks found in the literature are developed for use by private-sector organizations and organizations in general. This, therefore, leaves another gap, both in academic literature and practice, for organizations not addressed by existing frameworks.

The organizational practices from the 15 CRM frameworks under review are synthesized and categorized into sub-domain practices, domain practices, and STS dimensions in Table 3. The mapping exercise supports the propagation of the trend in cyber resilience research and practice, which has largely been focused on the technical aspects of cyber resilience. Only three of the frameworks fulfill the requirements of an STS entirely. When the social and technical dimensions of an STS are optimized in isolation or separately (sub-optimized), adverse cyber events can be caused by the socio-technical gaps resulting from the sub-optimization of the socio-technical whole.

The study further finds that more than half of the CRM frameworks are developed according to the cyber resilience management cycle despite not all of them proposing adaptive organizational practices in times of crisis toward a better resilient posture. The lack of operationalization of the *adapt* phase into organizational practices in some CRM frameworks may lead to a loss of opportunity to utilize knowledge and experience gained from an adverse event to become more cyber resilient in the future.

5.2 Conclusion and Future Work

This article has provided an introductory overview of existing CRM frameworks. A socio-technical approach to cyber resilience has been employed to frame the discussion about the gaps in the literature on CRM frameworks. The findings in this article represent the current state of the CRM frameworks in academic literature in terms of their affordances for guiding organizations' joint optimization process toward a resilient cyber posture and their operationalization of the four general cyber resilience management phases into cyber resilience organizational practices.

Our analyses revealed socio-technical gaps in the majority of the CRM frameworks in the literature. They emphasize more of the technical dimension of cyber resilience in favor of the social and environmental dimensions. Further, there is limited operationalization of the *adapt* phase of the cyber resilience management cycle into organizational practices in some CRM frameworks.

Finally, we also note that existing CRM frameworks are not intended to be a "one-size-fits-all" solution for organizations. They should be adapted to each organization's specific cyber threat landscape and cyber resilience needs. One particular gap found in this review that echoes previous studies is the absence of CRM frameworks that are developed for TSOs. Moving forward, employing a socio-technical cyber resilience approach to develop a CRM framework for TSOs is, therefore, an important research agenda.

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