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Sustainable Operation of Digital Infrastructure in the Smart City: Practical Experience and Implications

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1 ABSTRACT

In the rapidly evolving landscape of smart cities, the emphasis on leveraging data for urban development often overshadows the critical consideration of how IoT infrastructure will be operated and how Internet of Things (IoT) data is captured. This paper explores the essential elements of establishing a robust IoT network and platform as the foundation for Urban Data Platforms, highlighting the challenges associated with the operation of IoT networks and shows implications for a future operation of the the Smart City infrastructure. The paper delves into practical experiences, shedding light on the intricacies of sustaining digital infrastructure in smart cities. Specifically, it addresses the balance between the functionalities of IoT networks, the scalability of hardware, and the efficient capture of real-time IoT data. The discussion encompasses technological, environmental, and socio-economic aspects, emphasizing the need for a holistic approach to ensure the longevity and sustainability of these digital ecosystems. It states the point that municipal utilities and service providers play a pivotal role as operators of the physical component of the digital infrastructure in this context. Their responsibilities extend beyond the provision of IoT networks to ensuring reliability, scalability, and security. The significance of these actors as cornerstones for the successful implementation and ongoing operation of digital infrastructures in urban. Through an integrative approach, municipal utilities can serve as critical partners in addressing the challenges of urbanization in the era of the Internet of Things, laying the foundation for sustainable, liveable cities.

Keywords: Sustainable Operation, IoT, Digital Infrastructure, LoRaWAN, Smart City

2 INTRODUCTION

The ongoing urbanization and respective population growth pose significant challenges to cities worldwide. The concepts of Smart Cities offer innovative solutions to address these challenges and enhance the quality of life for urban populations worldwide. Besides the global perspective, the topic of Smart Cities raises further importance also for German cities, especially in the light of an emerging federal funding perspective, such as Modellprojekte Smart Cities (MPSC)[1]. Besides the societal implications of Smart Cities, it is important to understand how they leverage the integration of Internet of Things (IoT) technologies to enable intelligent connectivity of urban infrastructures and services. IoT infrastructures, connecting a variety of sensors and devices, form the foundation upon which an efficient and sustainable Smart City can be built.

The rapid development of IoT technologies and the increasing availability of sensors have resulted in cities having a multitude of data sources, enabling comprehensive monitoring and analysis of urban processes. These data-driven insights present new opportunities to increase efficiency, reduce resource consumption, and enhance the quality of life in cities. This includes on the one-hand side “typically” know Smart City use cases for the city itself, use cases such as Smart Parking, Smart Waste, but also Smart Metering Usecases, which are often in the focus of the legal duties for public services. In the urban landscape, digital infrastructure stands as an indispensable pillar of municipal services and as backbone for many other digital services, akin to traditional physical infrastructures like roads and transportation systems. Just as roads are foundational to physical mobility, digital infrastructure is indispensable for the digital mobility and connectivity essential to modern urban living. As cities evolve in the face of demographic shifts, the seamless functioning of digital infrastructure becomes increasingly vital for ensuring the overall well-being of residents. Much like the reliability of roads and transportation networks, the effective operation of digital infrastructure is paramount to guaranteeing access to essential services, facilitating communication, and sustaining the overall liability of urban environments. In the context of demographic changes, where the composition and needs of city populations evolve, the role of digital infrastructure becomes even more pronounced.

[1] Modellprojekte Smart Cities, BMWSB under https://www.bmwsb.bund.de/Webs/BMWSB/DE/themen/stadt-wohnen/staedtebau/smart-cities/smart-cities-node.html

In order to address these issues against the background of the maintenance of digital infrastrucutres, the paper is structured into five main sections. Firstly, it provides after the introduction an overview of the Components of the Digital Infrastructure, examining networking, hardware, and software systems pivotal in modern urban environments. Following this, leveraging Real-time-Data with IoT-Platforms as Foundation for Urban Data Platforms discusses the role of IoT platforms in collecting real-time data and establishing urban data platforms. Approaches in Operating a Digital Infrastructure then explores strategies for managing and operating digital infrastructures effectively. Maintaining a Smart City Infrastructure addresses challenges and strategies for sustaining smart city systems over time. Finally, the Conclusion summarizes key insights and findings, emphasizing the significance of digital infrastructure in smart city development and offering recommendations for future research and implementation.

3 COMPONENTS OF THE DIGITAL INFRASTRUCTURE

The focus of this scientific paper lies in the assessment of IoT and live sensor data as crucial part for a digital infrastructure. The development of live sensor data with IoT and it's potential for urban planning and management was seen and predicted already some decades ago even from a scientific perspective (WEISER, 1991) as well as in the popular discussion as "digital earth" (GORE, 1998). It was predicted, that the boundaries between sensors, computers, and mobile communication devices are increasingly disappearing and in addition to this, the ability to capture spatial data via spatial sensoring arises. These networked information systems are the first steps to a daily routine for the citizens, in which all entities of their environment are linked together in space and interact with each other. All of this produced and connected data will provide the way for the Internet of Things. Furthermore, this spatial relevant data could be made available for the public almost in real time (LIVE Singapore, 2011), which will make it possible, to gain very new insights about the functioning of a whole city. Even a decade ago, the potential use of live data was considered as foundation for a new "Science of Cities" (BATTY et al., 2012) and especially urban planners saw big potentials in making use of this data (EXNER, 2014). Besides the data processing capabilities, it is important to consider as well the necessary components of the layers of the digital infrastructure with its digital and physical components.

3.1 Interoperable layers of the digital Infrastructure for a smart city

Understanding digital infrastructure in layers is paramount for a comprehensive and effective approach to urban development. Each layer represents a distinct aspect of the complex digital ecosystem, from the deployment of sensors and communication networks to data management and the provision of smart applications. This layered perspective allows for a systematic and organized implementation, ensuring interoperability and scalability of the infrastructure.

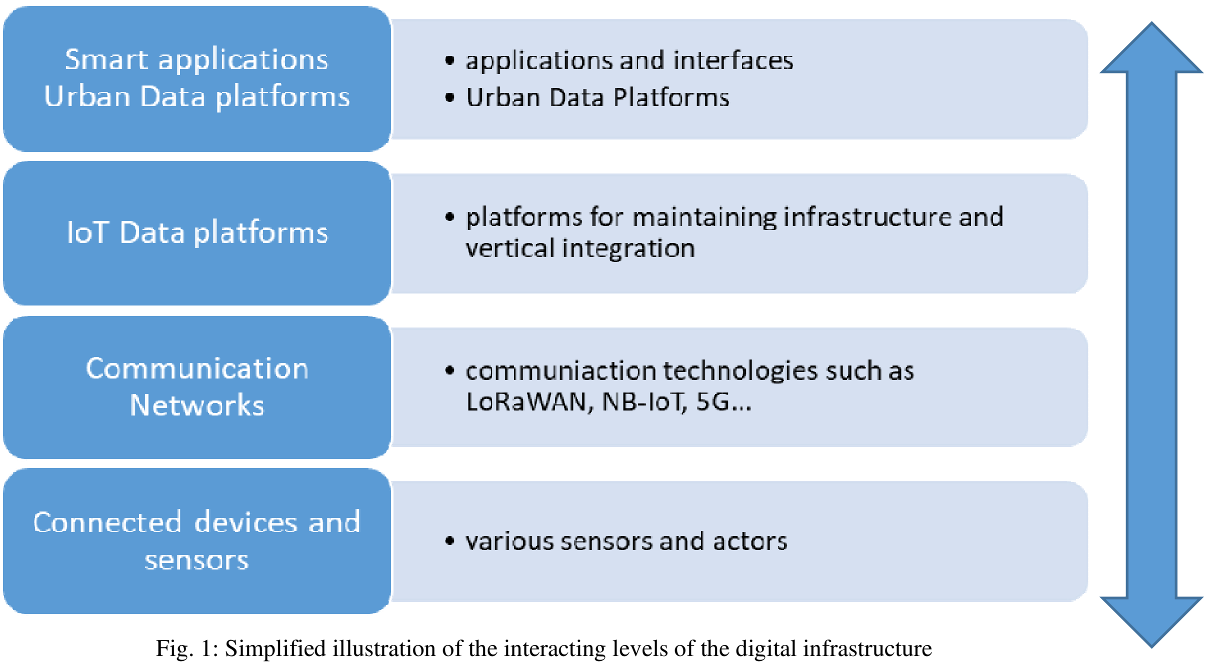

Fig. 1: Simplified illustration of the interacting levels of the digital infrastructure

By breaking down the digital framework into distinct layers, city planners and stakeholders from civil services can strategically address challenges at each level, optimizing resource allocation and facilitating the integration of new technologies. Moreover, a layered approach fosters a clearer understanding of the dependencies and interactions within the digital infrastructure, promoting resilience and adaptability in the face of technological advancements and evolving urban needs. In essence, viewing digital infrastructure in layers is fundamental for building a robust and sustainable foundation for smart cities, fostering innovation, efficiency, and an enhanced quality of life for urban residents. In addition, it is important to understand, that those layers work together modular, so that a different local authority could theoretically operate each element. This aspect is crucial to provide a long-term flexibility for the maintenance of the digital infrastructure. The respective layers are distinguished as follows:

3.1.1 Connected devices and sensors

In the era of smart cities, the seamless integration of connected devices and sensors into the urban fabric constitutes a cornerstone of the digital infrastructure. These devices, ranging from Internet of Things (IoT) sensors to advanced monitoring systems, form a sophisticated network that fosters real-time data collection, analysis, and transmission. This interconnected IoT enables cities to optimize resource utilization, enhance public services, and improve overall urban sustainability. From smart metering, smart traffic management to intelligent waste disposal, the deployment of these devices not only enhances efficiency but also paves the way for data-driven decision-making. Technically, this includes sensors and with the use of bidirectional protocols actors as well.

3.1.2 Communication Networks

Within the digital infrastructure of smart cities, communication networks serve as a critical layer, providing the essential connectivity that facilitates seamless interaction among various components. Particularly significant in this context are besides tradional cabel-oriented methods especially wireless technologies like WIFI, 5G, Bluetooth etc. low-power networks such as LoRaWAN® (Long Range Wide Area Network), which play a pivotal role in enabling cost-effective and energy-efficient communication for a myriad of IoT devices. LoRaWAN® technology stands out for its ability to support long-range communication while minimizing power consumption, making it ideal for the extensive and diverse deployment of sensors and devices across urban landscapes. In the realm of smart cities, organizations and entities have the flexibility to either act as their own connectivity providers or leverage services from third-party network providers. This bidirectional protocol allows the roles of „sensors“ and „actors“ for a tailored approach to connectivity management, offering the adaptability required to address the specific needs and scale of smart city initiatives. Whether cities choose to establish and manage their network infrastructure or opt for external connectivity services, the overarching goal is to establish a robust communication framework that underpins the seamless functioning of the digital ecosystem, fostering innovation, efficiency, and ultimately contributing to the realization of a truly smart and connected urban environment.

3.1.3 IoT Platforms for Data Management and Analysis

IoT platforms are technology frameworks designed to manage and enable the Internet of Things (IoT) devices and sensors. These platforms such as ZENNER Element IoT or Siemens Mindsphere, Azure IoT, AWS IoT provide the foundational infrastructure for connecting, collecting, and processing data from a variety of IoT devices distributed throughout the city. IoT platforms focus on facilitating communication between devices, managing data flows, and often include features like device management, data analytics, and application development interfaces specific to IoT. At this level, the collection, storage, and analysis of vast amounts of data captured by connected devices take place. Besides its software components, the maintenance of an IoT-platform often contains also the management of their crucial element – the gateways and sensors to run the network itself. Advanced analysis tools and algorithms are deployed to extract meaningful insights. As a crucial component, IoT platforms provide the infrastructure to connect and manage the various sensors and devices across the city, especially in a vertical perspective from sensor to platform. They facilitate data integration and play a vital role in the interoperability of the entire system.

3.1.4 Connected Urban Data Platforms

Urban data platforms, the linchpin of smart city ecosystems, serve as one central component with a horizontal orientation seamlessly integrating diverse data sources into a unified framework from different use cases, sources and public authorities. Besides live IoT Data from respective platforms, they connect also domain wide different data sources including for instance 3D city models or static demographic data. These platforms, often enhancing vertical structures of IoT platforms, act as the nerve centre for data-driven decision-making and operational efficiency. By aggregating information from various smart city components, such as IoT sensors and infrastructure systems, urban data platforms enable real-time insights into urban dynamics. Their role extends to optimizing resource allocation, enhancing sustainability through efficient resource management, and ensuring privacy and security in handling sensitive data. Positioned at the intersection of technology and urban governance, these platforms play a pivotal role in creating connected, responsive, and sustainable urban environments, driving innovation and improving the quality of life for citizens.

3.1.5 Smart Applications and Services

These are the applications and services based on the collected and analysed data. Examples include smart traffic control, energy management, environmental monitoring, smart building technology, healthcare services, and more. They can be fully or partly included within the existing platforms, or act as standalone apps. Smart applications and services constitute the dynamic interface of a smart city's digital infrastructure, translating data into tangible benefits for its inhabitants. These applications leverage the information collected by connected devices and sensors to enhance urban living in multifaceted ways. The embraces typical dashboards (Smart City Dashboards, Flood prevention dashboards…e.g.) but also dedicated apps or integrations in intelligent transportation systems that optimize traffic for instance. These applications streamline daily operations, improve efficiency, and create a more responsive urban environment. The integration on in services based on artificial intelligence (AI) opens up total new possibilities, but as today, the biggest potential is often seen by intelligent data services and alarming in a first step and further AI-based approaches that are more sophisticated. Embracing these smart solutions not only elevates the quality of life for residents but also contributes to the overall resilience and sustainability of the city.

4 LEVERAGING REALTIME-DATA WITH IOT-PLATFORMS AS FOUNDATION FOR URBAN DATA PLATFORMS

In the context of smart cities, the integration of Internet of Things (IoT) infrastructures plays a pivotal role in gathering real-time data and instant insights of the urban area. These infrastructures encompass a network of interconnected devices and sensors embedded within urban environments as described in the previous point. This paragraph highlights the aspects regarding IoT-infrastructures as real time data providers for further platforms and reflects practical insights from municipalities in the light data gathering of smart metering.

4.1 IoT infrastructures as the backbone of a Smart city

The Internet of Things (IoT) infrastructures constitute the foundational framework of a smart city, facilitating the interconnection of sensors and devices throughout urban areas to continuously gather data. This data, sourced from the physical elements of the digital infrastructure, assumes a pivotal role in shaping the real-time dynamics of smart cities, as evidenced by initiatives such as the "Live Singapore" project at MIT in Boston more than a decade ago (MIT Senseable City Lab, 2011). This project illustrates how ongoing data collection empowers urban authorities to make informed, data-driven decisions aimed at optimizing the efficiency of urban services. Additionally, the increasing significance of digitalization and transition within the energy sector will play a critical role in the context of smart cities. In the urban energy and utilities sector, the deployment of smart metering systems, for instance, facilitates the optimization of energy consumption (including water, electricity, heat, and gas) and the effective integration of renewable energies, which is pivotal for the energy transition. Monitoring these aspects is crucial for energy accounting, compliance with legal requirements, and the efficiency monitoring of the respective network.

Today, popular Smart City use cases, such as environmental monitoring facilitated by IoT sensors, enable real-time assessment of air quality and water levels or facilitating early detection and mitigation of environmental pollution for instance. In essence, IoT infrastructures lay the groundwork for a smart and interconnected urban environment, where data-driven applications contribute to sustainability, efficiency, and an enhanced quality of life for residents. IoT infrastructures establish the groundwork for urban data platforms that enable comprehensive analyses and data-driven decisions. An essential aspect of this is an cost-effective and flexible bidirectional Low Power data communication network such as LoRaWAN®. LoRaWAN® (Long Range Wide Area Network) is an open wireless communication protocol that enables energy-efficient and cost-effective networking of IoT devices over long distances. It allows sensor data transmission over several kilometers, ensuring broad coverage throughout the city (see more under LORA ALLIANCE, 2024). One facilitating aspect of LoRaWAN® access is the existence of the supporting alliance. The LoRa Alliance's support ensures interoperability among various devices and networks, streamlining development and deployment processes. Furthermore, the Alliance's expansive ecosystem encompasses a wide array of stakeholders, including cities, utilities, device manufacturers, network operators, and solution providers, fostering innovation and driving adoption. This collaborative environment accelerates the growth of the LoRaWAN® ecosystem, providing a competitive advantage over other low-power communication networks by offering scalable, cost-effective solutions tailored to meet the evolving needs of IoT deployments worldwide. While its technical specifications are comparable to other low-power communication networks, the open standard, the possibility for self-hosting, and therefore the massive global ecosystem are crucial points leading to widespread acceptance worldwide and a diverse market of sensors in various classes and price segments. The networking of sensors via LoRaWAN® enables real-time monitoring of urban processes. Sensor data is recorded in real time and transmitted to central data platforms, where it is analysed and converted into meaningful information. These data platforms serve as a central interface for urban decision-makers to retrieve information, identify trends, and implement data-driven measures within a network of data platforms such as urban data platforms.

4.2 Insights from practise in the light of urban utilities

The insights presented in this work are gained from practical collaborations from the authors with city municipalities and utilites tasked with overseeing their municipal infrastruct. Through hands-on experience and close partnerships, the authors have gained valuable first-hand knowledge of the challenges and opportunities inherent in managing urban infrastructure, especially in the context of smart metering. “Smart metering is the computerised measurement, determination and control of energy consumption and supply. Companies and private households are equally relevant. Smart meters are intelligent, networked meters for resources and energy such as water, gas or electricity” (GABLER, 2024) and one of the key tasks of monitoring their utilities. They facilitate efficient resource management by providing accurate and timely information, leading to improved resource allocation, reduced waste, and cost savings. Furthermore, smart meters empower residents and businesses by offering detailed insights into their resource usage, encouraging responsible and sustainable practices. The integration of smart meters into the broader ecosystem of smart city technologies enhances grid management, supporting reliable energy distribution and the integration of renewable sources. Additionally, smart metering contributes to environmental sustainability by monitoring and reducing the city's environmental impact through optimized energy consumption. Smart metering stands out as the most important business case within the realm of smart city use cases due to its (at least in Germany) legal duties and it fundamental impact infrastructure optimization, which is also considered in various customers surveys regarding the importance of IoT infrastructures for smart cities. From a legal perspective, the importance of smart metering lies in its potential to enhance regulatory compliance, data security, and operational efficiency. In many countries, traditional methods of data gathering from meters, such as manual reading or drive-by-methods, are not only resource-intensive but also prone to errors and delays.

Smart metering, particularly when integrated with IoT technologies like LoRaWAN®, offers a more cost-effective and reliable alternative for data collection. By enabling automated, real-time monitoring and reporting of utility consumption, smart meters ensure greater accuracy and timeliness in data acquisition, thereby enhancing transparency and accountability in regulatory compliance. Additionally, the adoption of IoT-enabled smart metering infrastructures presents opportunities for synergies and cost savings across various sectors. Beyond their primary function of utility metering, these infrastructures can serve as a foundational layer for supporting additional IoT applications and use cases, such as environmental monitoring, traffic management, and public safety. By leveraging the existing infrastructure for multiple purposes, municipalities can maximize their return on investment and unlock new avenues for innovation and efficiency in urban governance and service delivery. In the perspective of a city, it is always difficult to initially invest ressources (hardware, software and human ressources) run a usecase without a clear return of investment, if they will not have a dedicated funding. And if tender programs exist or a dedicated poilitical agenda, it has to be determined, that also the longterm operation is ensured as well. Therefore, from a legal standpoint, promoting the deployment of smart metering technologies with IoT integration not only ensures compliance with regulatory requirements but also fosters a more resilient and interconnected urban infrastructure ecosystem.

5 APPROACHES AND CHALLENGES IN OPERATING A DIGITAL INFRASTRUCTURE

The upcoming chapter embraces the aspects regarding running a digital infrastructure and its challenges that extend beyond the mere deployment of technology. Those insights were gained by the long-term work with many utilities and the corresponding exchange. The long-term operation adds another layer of complexity, necessitating strategies for sustainability and scalability to accommodate evolving needs and technological advancements. Moreover, maintaining different levels of maintenance across various components is another point, from routine upkeep to addressing unforeseen issues, demands robust strategies and resources. Emphasizing open data and open-source solutions presents additional challenges, including establishing protocols for data sharing and interoperability while balancing privacy and security concerns. Finally, the role of funding policies play a critical role, as securing adequate financial resources and establishing sustainable funding mechanisms are essential for the ongoing viability and growth of digital infrastructure initiatives.

5.1 Operation of physical components of the digital infrastructure

Cities are increasingly focusing on leveraging data for innovative solutions, emphasizing the "what can be done with data" aspect. Concurrently, public utilities traditionally concentrated on vertical issues, mainly generating data and maintaining network functionality. The value of the cost of data production by sensors in this light is often not fully envisaged. Besides gateway-related hardware services for instance, this embraces also battery replacements or sensor malfunction repairs. In the context of the sensor energy usage, the majority of sensors in the future will be wireless and low power networks will be play their important role. Of course, there are rapid developments in the light of sensors with energy harvesting methods, but this will not be the part for the majority of sensors. Every installed sensors needs respective resources (personal and financial) for its maintenance and it will be important to understand this, in order to prevent a scenario, that Mark Weiser's world of „Ubiquitous computing (and sensors)“ turns into a world of „ubiquitous and continuous hardware maintenance" at the physical parts of the digital infrastructure. This shift underscores the necessity for flexible operational models, especially in the realm of efficient maintenance management. With the deployment of sensors in public spaces and the successful scaling of digital data processing, a notable challenge arises in the shortage of adequately trained personnel for maintaining these elements. Best practices for efficient maintenance management must address this human resource gap, emphasizing training programs and streamlined processes to ensure the proper care and functionality of the tactile elements, such as sensors. The implementation of these practices is crucial for sustaining the reliability and longevity of smart city initiatives.

In the light of these concepts, it has to be considered, that the involved partners are not only the communities but in some case the utilies directly. In Germany, municipal authorities often wield significant power and possess ample resources for managing essential infrastructure within their jurisdictions. However, it is not uncommon for these authorities to operate somewhat independently, sometimes existing outside direct city control. This unique legal landscape frequently raises questions surrounding the most effective maintenance models for critical infrastructure. With municipal authorities holding substantial sway and resources, but operating autonomously, determining responsibility and accountability for infrastructure upkeep can become complex. The decentralized nature of governance can lead to fragmented approaches to maintenance and decision-making, potentially affecting the efficiency and effectiveness of infrastructure management. As a result, navigating these legal dynamics becomes crucial for establishing sustainable and coordinated maintenance models that ensure the continued functionality and resilience of essential urban infrastructure in smart cities.

The long-term operation and maintenance of IoT infrastructures are decisive factors for the sustainable success of a smart city. Municipal utilities, as established public service providers with extensive experience in the utilities industry, are predestined for the role of operator of smart city infrastructures. Their close connection to the local community and their long-term commitment to the city make them trustworthy partners for the management and maintenance of digital infrastructure. The involvement of municipal utilities as operators of IoT infrastructures also offers further advantages. As they already have established communication and supply networks, they can utilise these infrastructures to support the data transmission of IoT sensors. Through this integration, smart city applications can be seamlessly integrated into existing systems, resulting in a more efficient and cost-effective implementation. Public utilities also take responsibility for data security and protecting the privacy of citizens. Careful management of the data collected is crucial to gaining citizens' trust in smart city initiatives and ensuring the smooth operation of infrastructures.

5.2 Different levels of maintenance

The operational models for digital infrastructure demand a high degree of flexibility to accommodate the inherently diverse nature of urban landscapes and the varied operational capacities of city authorities and service providers. This flexibility is particularly crucial when addressing the tangible components of the infrastructure. In the smart city landscape, delineating responsibilities for maintaining specific components of urban infrastructure is crucial for effective operation. Notably in Germany, a practical approach has emerged, where municipalities, aligning with their governance and data management expertise, often operate urban data platforms. In contrast, public services take charge of IoT platforms, leveraging their domain-specific knowledge to manage connected devices and ensure seamless integration. This division of responsibilities fosters a collaborative ecosystem, optimizing efficiency and resource utilization while ensuring that each entity capitalizes on its unique competencies in maintaining a cohesive and well-functioning smart city infrastructure. Additionally, when it comes to maintaining the physical aspects of the infrastructure, such as sensors, flexibility becomes paramount. The physical components of these components necessitates maintenance protocols that are responsive to diverse urban environments and adaptable to the distinct operational procedures of different city utilities. This also goes along with the issue of resilience. Resilience in the light of Smart Cities is considered as crucial in many perspectives (BBSR, 2023). Cities and municipalities face a dual challenge: on the one hand, they are required to pursue ambitious climate protection and sustainability goals to ensure sustainable urban development. On the other hand, they must cope with the already noticeable adverse effects of climate change and limit its consequential impacts. Against this background, it is important to make resilience tangible as the framework for sustainable urban development. It explains why it can be effective to engage more deeply with this concept in the development of smart city strategies. Resilience can be developed both as an independent element of integrated sustainable urban development and as a crosscutting, theme and management principle embedded in smart city strategies.

5.3 Requirements in the light of standards, open data, data interface and open source

In the context of Smart Cities, the significance of standards, interfaces, and APIs (Application Programming Interfaces) is crucial, but will not be the focus of this scientific paper, but shortly considered in their thematic connection. Standards provide a common framework ensuring interoperability and seamless integration among diverse open-source solutions and proprietary systems. They establish a shared language, enabling different components of the Smart City ecosystem to communicate effectively. Standards also promote scalability and sustainability, allowing for the expansion of Smart City infrastructure without compromising compatibility. Interfaces and APIs serve as connections through which various applications and systems can interact. By providing standardized interfaces, interfaces, and APIs facilitate the smooth exchange of data and functions, enabling a more interconnected and efficient urban environment. Open data and open-source initiatives play pivotal roles in shaping smart cities, offering distinct advantages and encountering unique challenges. On the positive side, open data fosters transparency, enabling citizens to access and utilize government-generated information for innovation and awareness. It encourages collaborative problem solving, fuelling the development of diverse and impactful applications. Similarly, open-source solutions promote flexibility and cost-effectiveness in smart city projects, allowing customization and collaboration among developers. However, challenges arise in terms of long-term maintenance and support. Open-source projects may lack centralized governance, potentially leading to fragmented development or abandonment if they are not managed. This management has to be included, also from a business perspective. Ensuring ongoing support and updates may require dedicated resources from either the community or the adopting city. Balancing the advantages of community-driven innovation with the need for sustained maintenance remains a crucial consideration for the successful integration of open-source solutions in smart city environments. Hence, the role of standards and respective protocols is crucial, other questions regarding open source or commercial software has to be seen in the respective context.

5.4 Perspective of funding policies

The perspective of the federal funding policy has to be considered in this context, in addition, .The challenge faced by smart city funding policies is underscored by the call for a sustained, long-term perspective, surpassing the current emphasis on experimental projects. As mentioned in the beginning, the funding project of „Modellprojekte Smart Cities“ were an initial starting point to bring to topic of Smart Cities on most of the cities agenda. However, while recognizing the value of experimental designs for innovation, the realtion to crucial basic infrastructure such as networks, sensors, and communication systems is often not fully understood. Experimental projects can be faulted for operating in isolated locations and failing to encompass the entire urban population or infrastructure. Important is targeted funding policy prioritizing the development of a robust basic infrastructure, encompassing nationwide networks, energy-efficient buildings, and intelligent transport systems and not only lighthouses. This emphasis aims to facilitate seamless integration and scalability of diverse smart technologies. The goal is to bridge the gap between experimental designs and long-term urban development, thereby improving the quality of life and sustainability in German urban areas. This approach is positioned to be both compliant with the need for sustained, long-term development and flexible enough to adapt to the complex landscape of communities and civil services across Germany. However, the transferability is considered as important point, but the retrospective monitoring of such a program will show its implications for further funding activities.

5.5 Accountability of IoT service providers and defining the role of the service provider

In the context of smart cities, where IoT technologies are increasingly integrated into urban infrastructure, the principles of accountability and transparency are crucial to ensure that these advancements benefit citizens equitably and responsibly. City utilities emerge as pivotal players in this landscape due to their intimate understanding of local infrastructure and their direct engagement with the community. Through collaboration with IoT companies, city utilities can establish frameworks that prioritize accountability and transparency in the deployment and management of smart city technologies. This collaboration extends to addressing the complex issue of data ownership. As data generated by IoT devices becomes an invaluable asset in the development of smart cities, clarifying ownership rights is essential. City utilities, as custodians of public infrastructure and services, can advocate for data ownership models that prioritize the interests of citizens while also supporting innovation and economic development. By establishing clear guidelines and mechanisms for data governance, city utilities can ensure that data generated within the urban environment is ethically managed, securely stored, and leveraged for the collective benefit of the community. In this way, city utilities will play a pivotal role as trustful local actor in fostering public awareness and engagement regarding data ownership rights, empowering citizens to make informed decisions about their data and its use in the smart city ecosystem. In Germany, this goes along with the dual responsibility of Public Authortities. They must ensure the efficient provision of public services while also safeguarding the rights and well-being of individuals within their jurisdiction. This entails upholding high standards of service quality and accessibility, as well as protecting privacy, promoting equality, and upholding the rule of law. Through effective governance structures and transparency measures, they strive to fulfill these dual roles, also together in cooperation with companies from the private sector.

Similar to the water context where regulatory frameworks govern the operation of water distribution systems, it could be discussed, if the operation of IoT measurement points in smart cities may also benefit from a regulatory framework. Such a framework could provide guidelines and standards for data collection, usage, and privacy protection, ensuring that IoT devices deployed in urban environments adhere to ethical and legal principles. Moreover, a regulatory framework can promote interoperability among different IoT systems and facilitate data sharing between stakeholders, thereby maximizing the utility of smart city infrastructure. By establishing a regulatory framework for IoT measurement operations, city utilities and regulatory bodies can mitigate potential risks associated with data misuse, privacy breaches, and technological malfunctions, while also fostering innovation and investment in the smart city ecosystem. Though, the disacvantages of a more formal and legally fixed IoT world, which was very dynamic by its orgigns, has to be discussed as well.

6 CONCLUSION

In summary, achieving successful and sustainable operation of IoT for a smart city infrastructure relies heavily on a comprehensive understanding and strategic management of various factors, particularly in comprehending the different layers of digital infrastructure and its physical components. A crucial aspect is ensuring transparency in data costs, both in granularity and quantity, alongside considerations of how this data can be processed by AI methods, for instance. Given that live IoT data serves as the backbone of a smart city, it is imperative for operators to grasp and efficiently manage these costs. Highlighting the scalability advantages inherent in digital environments becomes crucial for optimizing expenses over time.

Within the context of smart cities, defining the roles for maintaining urban infrastructure is essential for efficient operation. Germany plays a special role in the international contect, because the role of public utitilities (The "Stadtwerke") as infrastrucutural provider is very strong and somehow unique in the international context. Thus, a noteworthy practice in Germany could be municipalities overseeing urban data platforms, leveraging their governance and data management expertise. Simultaneously, the public services handle IoT platforms, leveraging their domain-specific knowledge for seamless device integration and take care for their long-term maintenance with their respective ressources. This collaborative approach ensures optimal efficiency and resource utilization, with each entity focusing on its unique strengths to maintain a cohesive and effective smart city infrastructure. Furthermore, a key insight for long-term operators, such as municipal utilities, is the importance of prioritizing cost-effective base use cases. By strategically selecting foundational applications that strike a balance between efficiency and economic viability, such as smart metering, cities can ensure not only the functionality but also the longevity of their IoT infrastructure. This approach aligns with the overarching goal of smart cities to enhance urban processes and elevate the quality of life for citizens. Therefore, a forward-thinking perspective that integrates cost transparency and prioritizes economically viable use cases is paramount. Municipalities and operators must collaborate to establish a framework that not only meets the immediate needs of a smart city but also lays the groundwork for sustained, efficient, and resilient urban environments in the long run. In essence, the success of smart cities lies not only in the adoption of cutting-edge technologies but also in the astute management of resources and a commitment to sustainability at every level of infrastructure development and operation.

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