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Impact assessment of ICT solutions in EU Smart Cities and Communities projects: from niche innovations to socio-technical transitions

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Disclaimer

The writing process of this thesis involved the use of several digital tools. ChatGPT (OpenAI, GPT-4 and GPT-5 models) was used to refine English phrasing, improve grammar, and translate the English abstract into German. Microsoft Word Editor was applied for spelling and grammar checks, while Grammarly was used for final proofreading. Zotero was used for managing sources and references, and Canva was used to create own figures. All academic content remains the author's own work.

Abstract

To address urban and climate-related challenges, many cities are adopting smart city strategies in which Information and Communication Technology (ICT) plays a central role. This thesis examines the extent to which ICT solutions implemented in smart city projects influence socio-technical transitions. Special attention is given to the technical and social impacts of the solutions as well as to the barriers and enabling factors encountered during implementation. The study employs a qualitative case study approach, conducting an impact assessment of 78 ICT solutions across four EU Smart Cities and Communities (SCC) projects. The Multi-Level Perspective (MLP) served as the theoretical framework of the thesis, and an analytical model was developed to examine the findings across the niche, regime, and landscape level.

The findings reveal that most ICT solutions had impacts related to energy efficiency, emission reduction, and citizen awareness. However, the results indicate that the impacts are mostly constrained to the scope of the individual project (niche level), with limited influence on broader socio-technical systems (regime level). The thesis concluded that individual solutions had a modest impact on socio-technical transitions but that their combined effects could potentially and gradually influence established systems and contribute to broader socio-technical transitions over time.

Zusammenfassung

Um den städtischen und klimabezogenen Herausforderungen zu begegnen, verfolgen zahlreiche Städte Smart City Strategien, in denen die Informations- und Kommunikationstechnologie (IKT) eine zentrale Rolle einnimmt. Die vorliegende Arbeit analysiert, in welchem Ausmaß in Smart City Projekten eingesetzte IKT-Lösungen sozio-technische Transformationsprozesse beeinflussen. Dabei liegt der Fokus sowohl auf den technischen und gesellschaftlichen Auswirkungen der Maßnahmen als auch auf den während der Umsetzung auftretenden Hemmnissen und förderlichen Bedingungen. Methodisch wird ein qualitativer Fallstudienansatz angewandt, der eine Wirkungsanalyse von 78 IKT-Lösungen innerhalb von vier EU-Smart-Cities-and-Communities-Projekten umfasst. Als theoretische Grundlage dient die Multi-Level-Perspektive, auf deren Basis ein analytisches Modell entwickelt wurde, um die Ergebnisse auf der Nischen-, Regime- und Landschaftsebene systematisch zu erfassen.

Die Untersuchung zeigt, dass der überwiegende Teil der Lösungen Effekte im Bereich Energieeffizienz, Emissionsreduktion und Sensibilisierung der Bürger hervorruft. Gleichzeitig verdeutlichen die Befunde, dass sich diese Wirkungen größtenteils auf den Rahmen einzelner Projekte (Nischenebene) beschränken und nur begrenzten Einfluss auf umfassendere sozio-technische Strukturen (Regimeebene) entfalten. Abschließend wird festgestellt, dass die isolierten Beiträge einzelner Lösungen einen eher geringen Effekt auf Transformationsprozesse haben, ihre kumulativen Wirkungen jedoch potenziell langfristig bestehende Systeme verändern und so zu umfassenderen sozio-technischen Übergängen beitragen können.

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1. Introduction

1.1 Background

Urbanization is a global trend. Today, more than 55% of the global population lives in urban areas, and this percentage is expected to rise to 70% in 2050 (United Nations, 2023). In 2016, cities consumed around 75% of the world's resources and energy and were responsible for 80% of the global greenhouse gas emissions (Mohanty et al., 2016). Air pollution, waste management, traffic congestion, negative impacts on human health, resource limitations, and failing infrastructure are other common negative outcomes of urbanization (Silva et al., 2018). Simultaneously, cities are struggling with challenges related to climate change and global warming, such as rising temperatures and more frequent extreme weather events (United Nations Environment Programme, 2024).

To address these challenges, cities must develop and integrate innovative solutions in urban development and urban planning (Bibri & Krogstie, 2017). In recent years, smart city development has been widely recognized as a promising solution to these challenges (Blasi et al., 2022), with experts in both academia and industry acknowledging its potential to address urban challenges effectively (Silva et al., 2018).

A smart city is described by Silva et al. (2018) as an urban area that uses Information and Communication Technology (ICT) to improve the efficiency of various city processes and enhance the quality of services for its residents. These technologies can create and promote sustainable development practices to meet increasing citizen demands (Javed et al., 2022). However, while smart city solutions often contribute to more sustainable cities, their implementation does not always guarantee a positive impact on sustainable development (Blasi et al., 2022).

Multiple cities are already implementing smart city technologies (Javed et al, 2022), and over the past decade, numerous of smart city initiatives have emerged and advanced globally (Duygan et al., 2022). The European Union has played a major role in advancing the development of smart cities. Their funding program, Horizon 2020, supports over 20 Smart Cities and Communities (SCC) projects in Europe (European Commission, n.d.). These SCC projects are organized into four generations launched between 2014 and 2023. All SCC projects consist of Lighthouse cities and Follower cities. The smart city solutions are first implemented in the Lighthouse cities, whereby the objective is to replicate the successful solutions and their business models to the Follower cities (European Commission, n.d.).

A key component across all smart city projects, particular in the above-mentioned SCC projects, is the implementation of ICT. In the context of this thesis, ICT solutions encompass artificial intelligence (AI) integrations, digital twins, and urban data platforms. Furthermore, the Internet of Things (IoT) such as smart sensors and smart city lightning systems will also be a part of the broader term ICT.

1.2 Problem statement

As noted above, cities today face challenges related to rapid urbanization and climate change. Smart city development, and the implementation of various smart city projects with ICT solutions have emerged as an approach to solve these challenges. ICT solutions have the potential to improve energy efficiency, reduce emissions, and provide services to citizens (Kramers et al., 2014). Nonetheless, many ICT solutions are only tested in small-scale pilot projects and are rarely integrated into broader, existing city operations where they could have a larger impact and support wider socio-technical transitions (see chapter 3.2).

Moreover, while the concept of smart cities and ICT has been addressed in academic research, only a limited number of studies have been conducted on the actual impacts of specific solutions once they are implemented. Assessing these specific impacts is important because it shows how technologies can bring about change in society, rather than merely addressing their theoretical benefits. This understanding can clarify how ICT solutions influence socio-technical transitions and make research findings relevant for future smart city development. The lack of academic studies on this topic is further complicated by the rapid pace of technological change, which can make previous studies outdated already after a short period of time.

1.3 Objectives and research questions

The following thesis investigates whether and how ICT solutions, implemented in smart city projects, contribute to broader socio-technical transitions. This is examined by an impact assessment of ICT solutions implemented in four completed SCC projects funded under the

European Union's Horizon 2020 program. Rather than narrowing it down to a single technology, city, or impact, this thesis explores the broader picture of ICT solutions in diverse smart city projects and urban settings. By posing broad research questions, it simplifies identifying common patterns and comparing the impacts of ICT solutions across different contexts. The focus is on the technical and social impacts of the ICT solutions. The technical impact assessment evaluates how the ICT solutions affect provisioning systems through efficiency, technology, and environmental performance. The social dimension of the impact assessment examines how these ICT solutions influence citizens and urban governance. Finally, this thesis identifies common barriers and enabling factors for implementing ICT solutions, offering insights into what supports or hinders their impact and integration within provisioning systems. Based on these objectives, the primary research question guiding this thesis is:

RQ1: To what extent do ICT solutions, implemented in selected smart city projects, contribute to socio-technical transitions?

To answer this, two secondary research questions are explored:

RQ2: What are the most common technical and social impacts of ICT solutions on provisioning systems in selected smart city projects?

RQ3: What are the key enabling factors and barriers when implementing ICT solutions in smart city projects?

2. State of the art

2.1 Smart Cities

The definition of a smart city has been widely discussed in recent years. According to Silva et al. (2018, p.697), a smart city can be generally described as an urban environment where ICT and other technologies are used to enhance the efficiency of city operations and improve services for residents. Smart cities are also described as complex systems in which people, institutions, technology, the environment, and infrastructure are closely connected. Digital technologies such as IoT, AI, and digital twins can support new forms of urban governance, promote sustainability, and improve the quality of life for residents within these complex systems (Deng et al., 2021)

The term "smart city" was first introduced in 1994, but the smart city concept has evolved notably over the past two decades. Since 2010, the development of practical smart city projects and increased support from the European Union has promoted growth in the number of publications on this subject (Ahvenniemi et al., 2017). Initially, the smart city concept focused mainly on technology and integrating ICT into urban infrastructure, often through a top-down implementation approach (Batty et al., 2012; Ben Letaifa, 2015). At the time, this technology-focused vision was termed "intelligent cities" (Ben Letaifa, 2015). Other terms that describe smart cities include digital cities, virtual cities, and information cities (Batty et al., 2012, p.438). Over time, the concept has expanded to include social, economic, and environmental dimensions. For example, smart cities include the integration of human and social capital, citizen engagement, and institutional capacity (Ahvenniemi et al., 2017; Kummitha & Crutzen, 2017). A widely cited definition of smart city comes from Caragliu et al. (2011), who describe it as smart

> "when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" (p.70).

This holistic perspective shows that smart cities are multidimensional and integrate elements beyond smart technology. Other important aspects are smart economy, smart mobility, smart environment, smart people, smart living, and smart governance (Ahvenniemi et al., 2017).

Silva et al. (2018) presented an extensive review of main trends, characteristics, and challenges regarding smart city development worldwide. Their study underscores how smart cities have evolved from early concepts and how the concept continues to develop. So far, the concept has not yet been widely adopted worldwide, partly because of ongoing technological, economic, and governance challenges (Silva et al., 2018). Silva et al. (2018) present four key pillars of a generic smart city: institutional infrastructure, physical infrastructure, social infrastructure, and economic infrastructure (Figure 1).

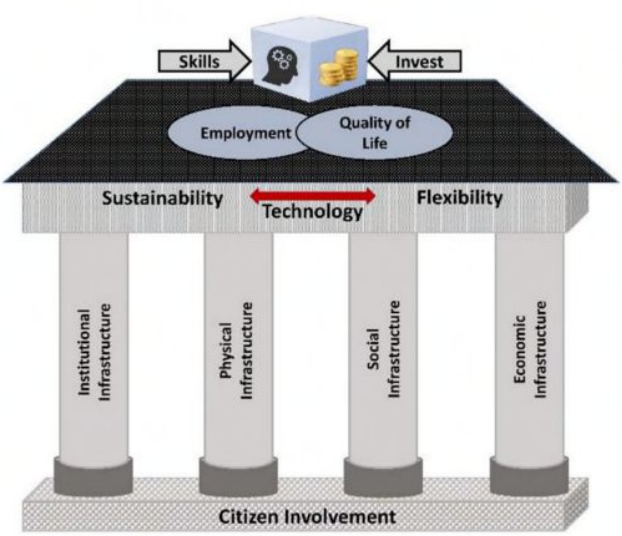

Figure 1. Four smart pillars of a generic smart city. Reprinted from Silva et al. (2018).

As shown in Figure 1, these pillars are interconnected and support the overarching goals of sustainability, flexibility, and technological advancement. The objectives are to enhance the quality of life and employment opportunities by leveraging investment and skills. Technology is depicted as a cross-cutting enabler that drives progress across all pillars, while citizen involvement forms the base and highlights the importance of public participation in smart city development. According to Silva et al. (2018), an effective smart city must integrate all these infrastructures to achieve sustainable urban development.

Recent literature on smart cities underscores how smart city initiatives often are developed linked with sustainability efforts (Ahvenniemi et al., 2017; Blasi et al., 2022; Huovila et al., 2022; Silva et al., 2018). Moreover, the concept of sustainable cities has gained more attention in research, leading to discussions about the differences between smart cities and sustainable cities.

Ahvenniemi et al. (2017) addressed this directly by analyzing the main features and assessment frameworks associated with each topic. By comparing sixteen frameworks involving eight focuses on smart cities and eight on sustainable cities, they reveal how the concepts prioritize different objectives and methods. As noted above, smart city frameworks tend to focus on implementing advanced technologies with the aim of increasing efficiency, economic growth, and social engagement. In contrast, sustainability frameworks focus more on environmental criteria, for instance, reduced emissions and ecological resilience. Ahvenniemi et al. (2016) also highlighted that while both sustainable and smart city initiatives seek to improve urban life, their approaches to assessment differ. Smart city projects often focus on quantifying outputs, for example, the number of digital platforms introduced or the number of technological devices. When monitoring sustainable cities, the evaluation is more focused on actual environmental outcomes. As a result, smart city initiative frameworks can sometimes overlook the broader impacts of technology on urban sustainability, whereas sustainability frameworks may fail to account for the benefits from digital innovation. Ahvenniemi et al. (2016) proposed the term "smart sustainable cites" to reflect frameworks that both consider the efficacy of technological innovations and their broader impacts on sustainability.

On a similar topic, Blasi et al. (2022) examined the links between smart city development and the United Nation's SDGs. By conducting a comprehensive literature review and bibliometric analysis, Blasi et al. (2022) identified areas where the smart city and SDG discourses overlap and where gaps remain. Out of 6072 documents on smart cities literature and 3113 papers within SDG literature, only 21 documents overlap. Their analysis shows that most research still separates smart cities and SDGs, and that the concept "smart sustainable city" is still at an early stage of acceptance.

2.2 ICT

As discussed above, smart cities address various urban challenges and sectors. However, a common feature across the literature is the role of ICT (Batty et al., 2012; Ben Letaifa, 2015; Deng et al., 2021; Kummitha & Crutzen, 2017).

ICT is a broad and evolving term, and there is no clear consensus regarding its definition (Charfeddine & Umlai, 2023). One definition used is from Masanet and Matthews (2010):

> "Information and communication technology can be broadly defined as systems whose fundamental functions are anchored in the generation, processing, storage, communication, and/or presentation of digital information" (p. 687).

ICT can be used as an umbrella term for multiple technologies involved in generating, processing, storing, and sharing digital information. This includes everything from personal computers and mobile networks to advanced sensor systems and software platforms (Charfeddine & Umlai, 2023). In the context of smart cities, ICT also includes integrated systems that allow analysis of real-time data to support urban services.

Within ICT, the Internet of Things (IoT) is one important application. IoT refers to the connection between everyday objects, for example streetlights, home appliances, or food (Madakam et al., 2015). IoT enables the collection of real-time data across networks of smart sensors (Bellini et al., 2022). In the smart city context, this is applicable in environmental monitoring, energy management, and mobility services (Bellini et al., 2022). Examples include measuring traffic flows with sensors in traffic lights, reducing waste with smart waste management systems, or using identification technologies of products in manufacturing (Li et al., 2015).

IoT devices generate large volumes of digital information, known as Big Data (Rathore et al., 2018). Big Data can, for example, be generated by smart homes, vehicles, social media, or sensors. Big Data is characterized by its volume and variety and can support decision-making processes in smart cities (Rathore et al., 2018). To manage these data, cities increasingly rely on urban data platforms that collect, analyze, and visualize data connected to city operations. These platforms can be essential for decision-makers, citizens, and research efforts (Barns, 2018). A data platform in the smart city context can take on many forms such as dashboards, web portals, or data marketplaces (Barns, 2018). A data platform is referred to as an open data platform when it is specifically designed to make data easily accessible and usable by a broad range of users in order to enhance transparency and enable data exploration (Osagie et al., 2017).

Digital twins are another important ICT development. Urban digital twins are virtual replicas of physical assets or places which are updated with data from IoT devices (Weil et al., 2023). In urban contexts, they can represent everything from buildings to entire cities. These virtual models are used for simulation, scenario analysis, and optimization in urban planning (Weil et al., 2023).

Digital twins can also support decision-making in areas such as infrastructure, energy management, and transport by providing city managers with real-time data (Mylonas et al., 2021).

AI is also a part of ICT, which has gained increasing attention in recent years. AI can use data programs that can learn from data and make decisions. It can analyze large amounts of data and provide insights, for example on energy consumption patterns (Pandiyan et al., 2023). Other applications of AI can be found in chatbots, cars, robots, and software agents (Cugurullo et al., 2024).

Energy control systems, smart metering, and smart grids are all discussed in ICT literature and are closely connected in the context of smart cities (Batty et al., 2012). Smart meters are advanced devices designed to measure and record real-time energy data. Energy control systems use these data to monitor energy demand and automatically adjust settings in buildings, so that energy is used only when needed (Pandiyan et al., 2023). All of this takes place within a smart grid, which is a digital electricity network that uses information from thousands of smart meters and sensors (Orlando et al., 2022; Pandiyan et al., 2023).

2.3 Previous studies

Several studies have examined the impact of ICT solutions and how they can foster sustainable transformation, especially in cities. Agboola et al. (2023) evaluated how ICT-driven solutions such as IoT and AI contribute to urban sustainability in Nigeria. Agboola et al. (2023) used equation modeling to better understand the role of ICT in enabling resilience and inclusive governance, especially in light of the rapid urbanization in the global south. ICT was shown to have a statistically relevant effect on stakeholder participation, energy efficiency, and urban planning. That study revealed that governments should invest in smart infrastructure that addresses environmental issues and enhances the quality of life of the citizens. This means ensuring that digital tools are affordable and easily accessible for everyone, including people with lower incomes or limited internet access. The authors also emphasized the need for clear systems to manage smart city projects efficiently and called for more research on long-term effects, how to scale ICT solutions in other cities, and how to protect citizens' data (Agboola et al., 2023).

Ipsen et al. (2019) conducted an environmental assessment of smart city solutions deployed in Copenhagen. The objectives of the study were to examine the environmental impact of seven smart city solutions using a combination of Urban Metabolism (UM) and Life Cycle Assessment (LCA) methodologies. UM tracks all the material flow in a city such as electricity, water, or waste, whereas LCA examines the full environmental impact of a solution from production and installation to usage and disposal. Some of these solutions include ICT such as smart windows, smart energy grids, sensorized waste collection, and smart water meters (Ipsen et al., 2019).

The findings showed that only one solution, the smart energy grid, reduced the environmental footprint in the city. Other solutions had limited or even negative environmental impact on urban systems. In some cases, this was due to the hidden impacts of the energy or materials required to produce the solution. The authors therefore concluded that smart city solutions are not automatically sustainable. Ipsen et al. (2018) underscored the importance of studying the full lifecycle of any technology before declaring it as sustainable.

While Ipsen et al. (2018) focused on quantifying the impacts of smart city solutions in Copenhagen, Kramers et al. (2014) aimed to categorize the broader potential of ICT solutions to reduce energy consumption across urban systems. The study's main objective was to identify where in urban systems ICT could be most effectively applied to enhance sustainability. The authors conducted a LCA and developed a framework that linked household energy use to potential ICT platforms. A typology of four ICT functions was introduced: automation, visualization, knowledge sharing, and system integration. By mapping these functions onto energy-intensive household activities such as heating, lighting, mobility, and food, the authors were able to identify "hotspots" where ICT could enable the most efficiency savings. Kramers et al. (2014) concluded that ICT effectiveness depends on how well it is embedded in larger socio-technical systems (see chapter 3.1). Therefore, technology alone is insufficient but also requires behavioral change and supportive governance structures.

Other studies investigated how to consistently measure and compare these types of smart city solutions. Huovila et al. (2019) analyzed and compared international indicator frameworks to help city planners, policymakers, and researchers to choose the most suitable one to evaluate smart city initiatives. The authors highlighted the lack of harmonized indicators. Furthermore, cities in early stages of digital transformation may benefit from more output-focused metrics, whereas more advanced cities should reflect on the actual impact and systematic change (Huovila et al., 2019).

In addition to scientific literature, several evaluation studies have been conducted within the EU's SCC program. One such example is the Consolidated Impact Assessments by the Scalable Cities Secretariat to assess the outcomes of the SCC projects (Etminan et al., 2024). The impact assessment reports serve as a cross-project analysis of several KPIs from four projects at that time. The assessment primarily used data collected through the so-called Self-Reporting Tool (SRT), which is a framework in which each SCC project can report progress against a common set of KPIs (European Comission, n.d.). The assessment reviewed three major domains: energy, mobility, and ICT. Due to a lack of data in the SRT, the assessment also included a qualitative document review of public deliverables. The report highlighted key impacts per Lighthouse City, for instance CO_2 reduction, number of electric vehicles implemented, or smart lampposts installed. While the consolidated impact assessments focus mainly on quantitative performance indications, this master thesis takes a qualitative and analytical approach. Moreover, this thesis focuses on the impacts of individual solutions rather than the overall results per project.

In addition to the Scalable Cities Secretariat, individual SCC projects often conduct their own project-related impact assessments. These evaluations typically focus on measuring the performance and outcomes of their own solutions. These assessments, however, do not compare their results with other projects. In this thesis, the project-specific impact assessments will serve as a key source of data.

3. Theoretical framework

The main objective of this thesis is to assess how ICT solutions implemented in smart city projects can influence socio-technical transitions. To explore this, the Multi-Level Perspective (MLP) is used as the theoretical framework. This chapter first introduces the concept of socio-technical systems, then socio-technical transitions, and finally the MLP and its three analytical levels.

3.1 Socio-technical systems

Loorbach et al. (2017) underscored that three types of systems are involved in societal change. One of these is socio-technical systems, for example systems involving energy, mobility, water, and waste. The other two are socio-economic systems, for instance regarding education, labor, and finance, as well as socio-ecological systems, which include agriculture, forestry, and fisheries (Loorbach et al., 2017). This thesis focuses on the socio-technical systems and the respective impact of ICT solutions in smart cities.

Socio-technical systems are interconnected networks of technologies, actors, institutions, and practices that bring together key societal functions such as transport, energy, communication, or food (Geels, 2004). While earlier definitions of innovation systems focused mainly on the production of technologies, Geels (2004) highlighted how socio-technical systems include both the production, diffusion, and use of technology. Actors on the supply side include firms, research institutes, universities and policy makers, and demand-side actors include interest groups, users, and media (Geels & Kemp, 2007). Socio-technical systems can be described as complex and unpredictable because they are shaped by innovation, political dynamics and cultural shifts (Köhler et al., 2019). Geels (2004) highlighted how technology plays a central role in socio-technical systems and why it is useful to distinguish the production, distribution, and use of technology as separate sub-functions within the system. Since the sub-functions within a system are closely linked to one another, changes in one area can often affect the whole system (Markard et al., 2012).

In the present thesis, the term *provisioning systems* refers to the socio-technical systems that deliver essential urban services such as energy, transportation, and digital infrastructure. According to O'Neill et al. (2018), provisioning systems include physical components and social components. Physical components are for example infrastructure and technologies, whereas social components include governance institutions, market, and community networks (O'Neil et al., 2018). In this thesis, the impact of ICT solutions on provisioning systems refers to how ICT can influence city-specific functions such as the energy sector, traffic, waste, markets, and governance.

3.2 Socio-technical transitions

A shift in a socio-technical system is referred to as a socio-technical transition. A transition includes changes in economic, technological, cultural, or institutional dimensions (Markard et al., 2012). They involve many actors and can lead to new products, services, and business models that either replace or reshape existing ones (Markad et al., 2012). For example, a shift in transport modes, from carriages to automobiles, sailing ships to steamships, or engine aircrafts to jetliners, can be analyzed as socio-technical transitions (Geels, 2005). Such transitions can develop over several decades (Geels, 2019).

Socio-technical transitions are related to, but differentiated from, technological transitions. Technological transitions focus on the technological dimension and do not include institutional arrangements or user practices (Markard et al., 2012). Innovations in socio-technical transitions include both technical and non-technical elements. Furthermore, they influence both the specific system of the innovation and broader areas of the society such as citizens everyday life, housing, and policymaking (Markard et al., 2012). A socio-technical transition can be understood as a sustainability transition if certain criteria are met.

(Geels, 2011) described sustainability transitions based on three characteristics. First, sustainable transitions are goal-oriented and aim to address environmental problems rather than merely emerging from market-driven innovation. Second, sustainable innovations often lack short-term user benefits and may therefore underperform compared to existing solutions (Geels, 2011). This means that they often require supportive policy frameworks, for instance subsiders or regulations, and these can face political resistance. Third, this type of transition typically occurs in sectors such as energy, transport or food, which are dominated by large companies with significant resources and influence. These companies are often tied to existing infrastructure and systems, which poses a barrier for the transition to occur (Geels, 2011).

This thesis focuses on sustainable, socio-technical transitions through the lens of the MLP.

3.3 Multi-level perspective

Using the MLP is a common approach in transition studies (Köhler et al., 2019). MLP is primarily discussed by Geels (2004, 2011, 2019) but was introduced earlier by Rip and Kemp (1998) and others. This framework aims to understand and explain how transitions unfold through the interaction of processes at three analytical levels: niches, socio-technical regimes, and socio-technical landscapes (Köhler et al., 2019). These three levels interact over time and while socio-technical transitions may vary between sectors, the core logic is the same (Geels, 2019). Niche innovations slowly gain strength and, at the same time, broader changes in the landscape level create pressure on the existing regime. If the pressure destabilizes the regime, it opens the opportunity for niche innovations to disrupt the existing socio-technical system. As niche innovations stabilize and align with elements of the existing regime, they can evolve into the new dominant structure. Over time, these new innovations may also influence developments on the landscape level (Geels, 2019) (Figure 2). The three levels in the MLP theory are explained in more detail in the following subchapters.

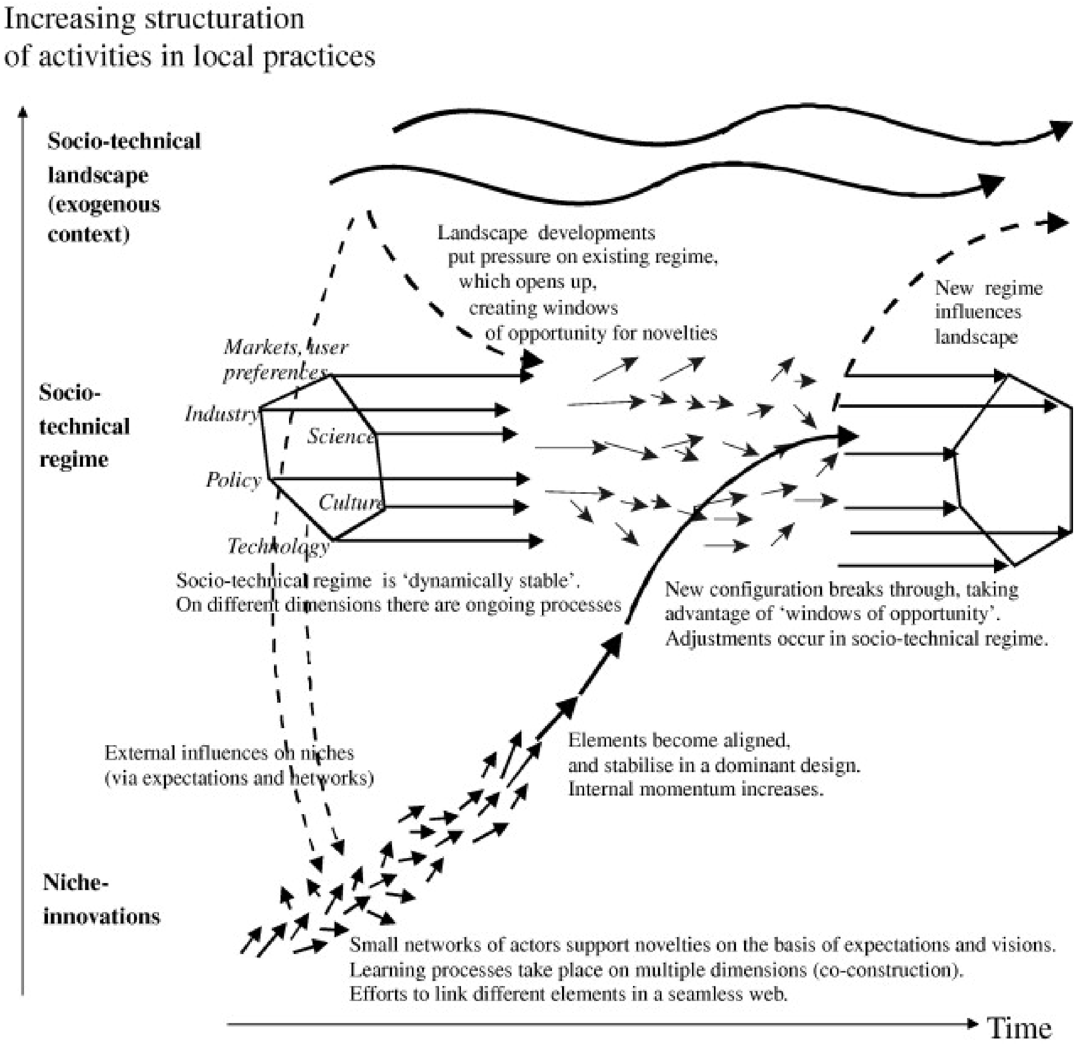

Figure 2. Multi-level perspective on socio-technical transitions. Reprinted from Geels (2011).

3.3.1 Niche level

Innovation begins in niches, which can be described as protected environments in which new ideas and technologies can be developed without direct competition from existing systems (Geels, 2012; Kemp et al., 1998; Markard et al., 2020). Examples of such protected environments are research laboratories, pilot projects or specialized markets (Geels, 2012). Niches typically emerge at the local scale, in contrast to regimes that represent the national scale and landscapes that reflect the global scale (Markad et al., 2020). Niches are important for transitions because they can be seen as the starting point for system change (Geels, 2011).

Within niches, radical grassroot innovations can take shape. These innovations often differ significantly from the technologies and practices found in the mainstream regime systems at the time (Geels, 2012). Examples of radical innovations are electric vehicles, plant-based milk, renewable electricity and smart meters (Geels, 2019). Geels (2019) differentiated four types of innovations: radical technical innovation, grassroots and social innovation, business model innovation, and infra-structural innovation. Table 2 provides examples of these four types of innovations in the mobility and energy sector.

Table 1. Different types of innovation on the niche level.

	Mobility	Energy
Radical technical innovation	Battery-electric vehicles, (plug-in) hybrid electric vehicles, biofuel cars; hydrogen cars	Renewable electricity (wind, solar, biomass, hydro), heat pumps, passive house, biomass stoves, smart meters
Grassroots and social innovation	Car sharing, bike clubs, modal shift to bicycles and buses, tele-working, tele-conferencing	Decentralized energy production ('prosumers'), community energy, energy cafés
Business model innovation	Mobility services, car sharing, bike sharing	Energy service companies, back-up capacity for electricity provision, vehicle-to-grid electricity provision
Infra-structural innovation	Intermodal transport systems, compact cities, revamped urban transport systems (tram, light-rail, metro)	District heating system, smart grids, bio-methane in reconfigured gas grid

Source: Own illustration. Adapted from Geels (2019)

New technologies, generated in niches, are typically underdeveloped in their early stages (Geels, 2002). They can be expensive, perform poorly, or seem impractical (Geels, 2002). Accordingly, it is important that niches serve as protected spaces in which innovations are protected from normal market pressures. In this manner, innovations can develop under alternative expectations and rules (Geels, 2002). Actors on the niche level often include entrepreneurs and start-ups, who play a key role in developing and promoting radical innovations (Geels, 2011).

3.3.2 Regime level

The socio-technical regime represents the underlying structure and stability of existing socio-technical systems (Geels, 2011). The linkages within the socio-technical systems are shaped by the social groups that create and reproduce them. The actors could be users, firms, policymakers, and interest groups (Geels, 2011). The concept of socio-technical regimes helps explain how the activities within these systems are coordinated and aligned (Geels, 2002). Regimes consist of shared rules and routines such as beliefs, practices, competencies, and institutional arrangements (Geels, 2011).

Rip and Kemp (1998) describes technological regimes.

> "A technological regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures" (p. 340).

Regimes are typically resistant to change due to strong, so-called lock in-mechanisms (Geels, 2019). A lock-in mechanism could be techno-economic, social and cognitive, or institutional and political. Examples of techno-economic lock-in mechanisms are sunk investments in infrastructure that create a strong interest in maintaining the status quo. A social lock-in mechanism could be old user practices and lifestyles, while political lock-in mechanisms could be existing regulations and networks. Table 2 shows examples of lock-in mechanisms based on Geels (2019, p. 189)

Table 2. Overview of lock-in mechanisms

Techno-economic lock-in mechanisms	(a) sunk investments (in competencies, factories, infrastructures) that create vested interests against transitional change (b) low cost and high-performance characteristics of existing technologies due to economies of scale and decades of learning-by-doing improvements.
Social and cognitive lock-in mechanisms	(a) routines and shared mind-sets that 'blind' actors to developments outside their focus (b) 'social capital' resulting from alignments between social groups (c) user practices and life styles, which have become organized around particular technologies
Institutional and political lock-in mechanisms	(a) existing regulations, standards, and policy networks favor incumbents and create an uneven playing field (b) vested interests use their access to policy networks to water down regulatory change and hinder radical innovation

Source: Own illustration. Adapted from Geels (2019).

Despite these lock-in mechanisms, innovation can still occur within the regime, but then it tends to involve gradual improvements in existing paths rather than radical change (Geels, 2002; Geels, 2011). The existing paths can be across various domains, for example, science, policy, culture, industry, and technology. Although each domain has its own sub-regimes, they also influence and interact with each other. The concept of the socio-technical regime captures the overall coordination between these domains and sub-regimes. When the sub-regimes work in the same direction, the whole system becomes more stable. However, sub-regimes that are separated in different directions result in instability. (Geels, 2004). The second case can open up opportunities for changes to take place (Geels, 2011).

3.3.3 Landscape level

The third level in the MLP is the socio-technical landscape. The term "landscape" is used to highlight the stable and material aspects of society, for example, the design of cities, infrastructure, and built environments (Geels, 2004). The landscape level refers to the external context in which regimes and niches are embedded. In comparison to regimes, the landscape level represents a broader set of factors that are even more difficult to change. These changes also tend to occur more slowly than those within the regime (Geels, 2002).

The socio-technical landscape includes macro-level trends and developments, such as demographic shifts, cultural values, political ideologies, economic cycles, and environmental pressures (Geels, 2002; 2011). Niche and regime actors cannot easily influence these factors over the short term (Geels, 2011). Importantly, the landscape can influence the dynamics and interaction between niches and regimes (Hinrichs, 2014). Geels (2012) differentiates two types of landscape pressures: destabilizing and stabilizing pressures. When analyzing the transport sector, Geels (2012) identified discussions of climate change, peak oil, and the diffusion of ICT as destabilizing pressures on the landscape level. Stabilized pressures, in contrast, were car-specific urban infrastructure, macro-economic growth and globalization with increased mobility demand.

The MLP helps to explain how transitions develop when processes at the niche, regime, and landscape level interact. As noted above, there is a general pattern involving three steps. 1. Niche innovation gradually gains momentum. 2. External landscape developments, together with niche innovations, put pressure on the existing regime. 3. When the regime is destabilized, a window of opportunity opens for niche innovations to spread and potentially change the system. (Geels, 2019). This is illustrated in Figure 2.

3.3.4 Critiques of MLP

Although the MLP is a widely used framework for analyzing sustainability transitions, it has also been criticized in the academic literature (Geels, 2019; Genus & Coles, 2008).

Genus and Coles (2005) presented several points of critique. For instance, they criticized that the boundaries across the three levels are often unclear, which makes it difficult to operationalize them in empirical research (Genus & Coles, 2008). This results in challenges when comparing findings across different sectors. Genus and Coles (2008) also critiqued the way transitions are defined because their start and end often depend on the researcher's interpretation. Moreover, not all research using the MLP is focused on the same questions, which also makes it more difficult to compare results.

Another critique point is that MLP has a strong focus on technology and structures, and thereby risks leaving out social aspects. Critics argue that by paying less attention to individuals and power dynamics, the MLP sometimes makes transitions look more automatic than they are (Genus & Coles, 2008). Several authors further highlighted how transitions are often complicated and shaped by negotiations among many different actors (Avelino & Rotmans, 2009; Shove & Walker, 2007), making them difficult to analyze. Genus and Coles (2008) also noted how many MLP studies are based on historical data that might not always be well-documented or analyzed from a critical perspective.

A recent suggestion is that the MLP could be improved by including ideas from other theories, for example the social construction of technology (SCOT) or actor-network theory (ANT). Various authors discussed how these perspectives can help bring more focus on human agency, power and the way technology and society interact (Elsner et al., 2023; Fiala & Jacob, 2024; Genus & Coles, 2008).

Much of the criticisms raised by Genus and Coles (2008), such as the lack of attention to power, agency, and the role of politics, have been addressed in later work on the MLP. Geels (2019) acknowledges the various criticisms of MLP and highlights how the framework has evolved as a result. For example, recent research on MLP now tries to better understand policy development, power struggles, and resistance from actors (Geels, 2019). Furthermore, recent research on the MLP integrates insights from discourse theory, which emphasizes how different actors use narratives and frames to influence the public and policymakers during transitions. Geels (2019) also underscores that the MLP now allows for different types and speeds of transitions and that the framework examines not only how new systems emerge, but also how old systems decline and are phased out.

3.4 Final theoretical framework

This thesis uses the MLP as a guiding framework to explore how ICT solutions in smart city projects contribute to socio-technical transitions. The MLP facilitates the analysis by organizing the findings across the three levels: niches in which the ICT solutions emerge and are developed; regimes that represent established systems and lock-in mechanisms; and the landscape, which includes broader, external developments.

Two adapted analytical models based on the MLP are developed for this thesis (Figure 3 and 4). The first figure (Figure 3) is an adapted version of Geel's (2011) original MLP diagram, modified to align with the scope of this thesis. That figure illustrates ICT solutions as niche innovations with the potential to grow and influence existing regimes, illustrated by the arrows. The existing systems at the regime level include various elements such as market and consumer preferences, industry, science, policy, culture, and technology. The circle around technology highlights the focus of this thesis on the development of ICT innovations. Importantly, ICT solutions may also influence other elements. Landscape pressures are shown as external forces that can destabilize regimes and create windows of opportunities for niche innovations to enter and change existing regimes. The figure also illustrates that ICT solutions with low impact on provisioning systems are unlikely to progress beyond the niche level or to influence the regime.

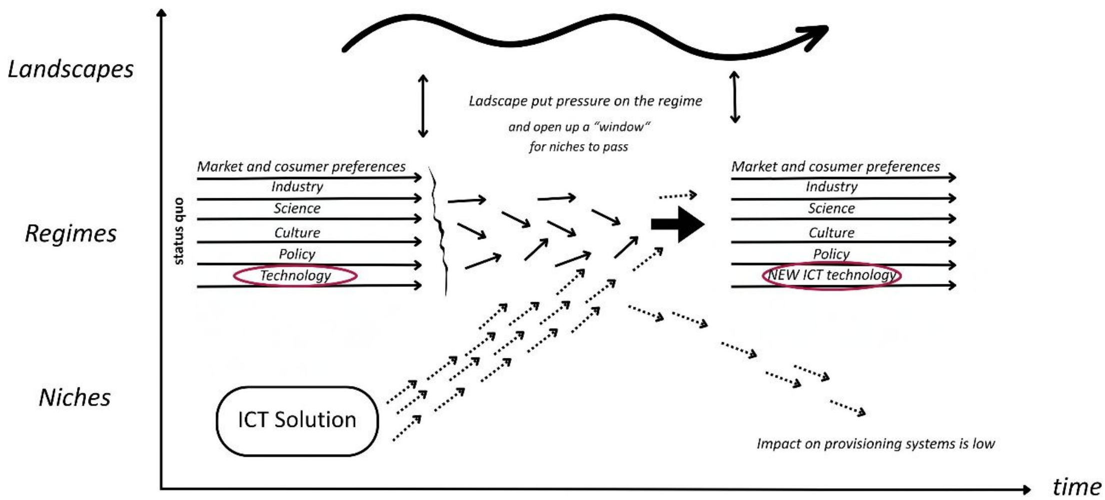

Figure 3. ICT in the MLP. Own illustration, adapted from Geels (2011) model.

The second analytical model in this thesis is used to operationalize the empirical findings, allowing them to be analyzed through the lens of the MLP. Figure 4 is divided into three colored sections, each representing one of the MLP's levels: niches, regimes and landscapes.

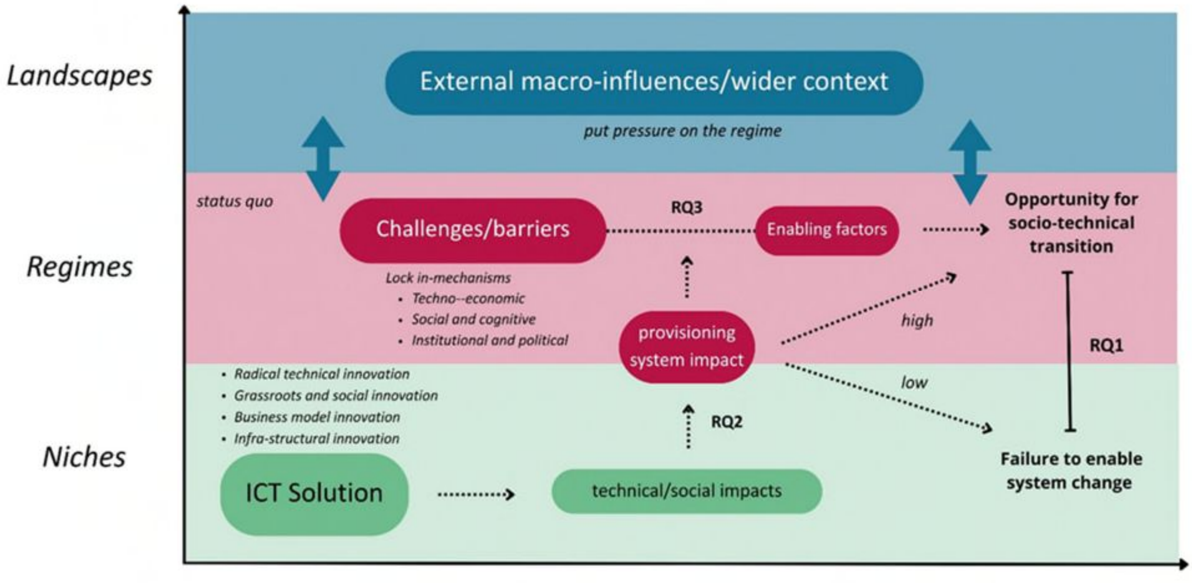

Figure 4. Operationalization, own analytical model.

The ICT solutions from the smart city projects are positioned at the niche level according to their type of innovation. Those solutions could be a radical technical innovation, grassroots and social innovation, business model innovation, or infra-structural innovation. The ICT solutions' social and technical impacts are also assessed at the niche level, primarily addressing RQ2[1]. Above the niche level, the regime level represents current socio-technical systems. The regime section of the model helps identify both the challenges (lock-in mechanisms) and enabling factors that influence the integration of ICT solutions into existing provisioning (socio-technical) systems. The analysis on the regime level aligns closely with RQ3[2]. The illustration shows how some innovations may progress from the niche to the regime level if the (positive) impact on provisioning systems is large enough. Enabling factors are also marked as a contribution to reach opportunities for socio-technical transitions.

[1] RQ2: What are the most common technical and social impacts of ICT solutions on provisioning systems in selected smart city projects?

[2] RQ3: What are key enabling factors and barriers when implementing ICT solutions in smart city projects?

The landscape level, the blue area at the top of the figure, encompasses external, societal influences when integrating these ICT solutions. These could be policy regulations, economic trends or other factors that have in some way influenced the implementation of the solutions. These external factors can put pressure on the regime. Such external pressures are represented by arrows between the landscape and regime level. The arrows symbolize how broader factors can either drive change by destabilizing the regime or reinforce the status quo.

The vertical line on the right side of the model represents the extent to which ICT solutions can influence socio-technical transitions, which corresponds to RQ1[3]. Opportunities for socio-technical transitions occur when three conditions are met: 1) The regime is destabilized by external pressures; 2) The ICT solution shows positive technical and social impact and has a strong impact on established provisioning systems; 3) The challenges/lock-in mechanisms within the regime level are not too overwhelming and there are enough enabling factors to help the solution spread its impact. Here, failure to fulfil these conditions hinders system change.

This framework aligns with the research questions of the thesis. It enables an analysis of the most significant impacts of ICT solutions (RQ2) and identifies barriers and enabling factors (RQ3). By addressing these questions, it facilitates the investigation how ICT solutions, in smart city projects, may contribute to socio-technical transitions (RQ1).

[3] RQ1: To what extent do ICT solutions, implemented in selected smart city projects, contribute to socio-technical transitions?

4. Methodology

4.1 Research design and approach

A qualitative research design was adopted to address the research questions and objectives of this thesis. The choice for a qualitative approach emerged from the fact that the study is structured as an analytical impact assessment. Qualitative methods are most appropriate when the aim is to explore and understand the major technical and social impacts of various ICT solutions, and how these solutions can influence socio-technical transitions. Here, the qualitative methods encompass case studies and document analysis (chapter 4.2). The data collection consists of secondary qualitative material, such as project deliverables and reports, gathered through desk research.

The choice of a qualitative research design is also justified based on the selected theoretical framework. Understanding the dynamics between niches, regimes, and landscapes in the MLP requires using data sources that include information beyond solely numerical indicators. Qualitative research allows the inclusion of public deliverables, best practices books, and other narrative descriptions.

This thesis applies an exploratory approach as it seeks to explore and assess the impacts of ICT solutions implemented in smart city projects. At the same time, it incorporates descriptive elements because it systematically describes monitored ICT impacts. In descriptive research, researchers observe and describe the phenomena without directly influencing them (Creswell & Creswell, 2017). In this thesis, the ICT solutions and their impacts are collected and then described as they occur, without any interventions or modifications.

Finally, this study follows an abductive approach to reasoning. This means moving between theoretical concepts and empirical findings. The use of the theoretical framework is influenced by and influences the collected data throughout (Bell et al., 2019, p. 24). Accordingly, the abductive reasoning can be seen as a middle ground between deductive logic, which involves testing hypotheses derived from existing theory, and inductive reasoning, which builds the theory based on patterns observed in the empirical data (Bell et al., 2019, p. 22-24). Abductive reasoning enables researchers to adjust the theory, empirical focus and/or research questions during the process of the study. Abduction therefore involves continuous and balanced engagement with both data and theory (Thompson, 2022).

The thesis process began with an overview of the MLP framework to better understand socio-technical transitions. Rather than strictly following the theoretical framework, the MLP serves as a guiding lens for shaping the data collection method and data analysis.

4.2 Research method

Case studies are the primary method for this thesis. Case studies are an appropriate method when the boundaries between a phenomenon and its context are unclear (Yin, 2009, p. 3). Given the complexity of socio-technical transitions, this method can facilitate the analysis. Case studies are further useful for investigating phenomena that occur in new or uncommon contexts, where existing knowledge is limited (Eisenhardt & Graebner, 2007). Case studies are a suitable method for this thesis because the integration of ICT solutions in smart cities and their influence on socio-technical transitions remains a relatively new and understudied area. Yin (2009, p. 53) further notes that using multiple cases can strengthen the results by making the findings more compelling and the study more robust. This case study analysis, therefore, includes four closed smart city projects.

4.2.1 Case study selection

Four completed SCC projects were selected: GrowSmarter, RUGGEDISED, MAtchUP and SPARCS. All four projects are funded by the EU funding program Horizon 2020. These projects were selected based on several key criteria:

- The completion of the project
- The availability of publicly accessible data
- Representation across different generations through Horizon 2020
- The project's range of various types of ICT solutions

The selected projects consist of 2-3 Lighthouse Cities and 4-5 Follower Cities each. The focus here is solely on the implemented ICT solutions in the Lighthouse Cities. The Lighthouse Cities in the four selected projects are: Stockholm, Cologne, Barcelona, Rotterdam, Umea, Glasgow, Valencia, Dresden, Antalya, Espoo and Leipzig. These cities represent a geographical diversity that made them suitable for an impact assessment.

While all projects fall under the broader SCC initiative, each project belongs to a distinct funding call, i.e., they were selected and financed through separate proposals under the Horizon 2020 program. According to the CORDIS database (European Commission, n.d-a), GrowSmarter was a part of the H2020-SCC-2014 call, and the project ran between 1 January 2015 and 31 December 2019. RUGGEDISED is linked to the H2020-SCC-2016-call and spanned from 1 November 2016 to 31 October 2022. MAtchUp was funded under the H2020-SCC-2017 call and ran from 1 October 2017 to 20 September 2023. Lastly, SPARCs, funded through the H2020-LC-SC3-2018-ES-SCC call, started on 1 October 2019, and closed on 30 September 2023 (European Commission, n.d.-b) (see Figure 5).

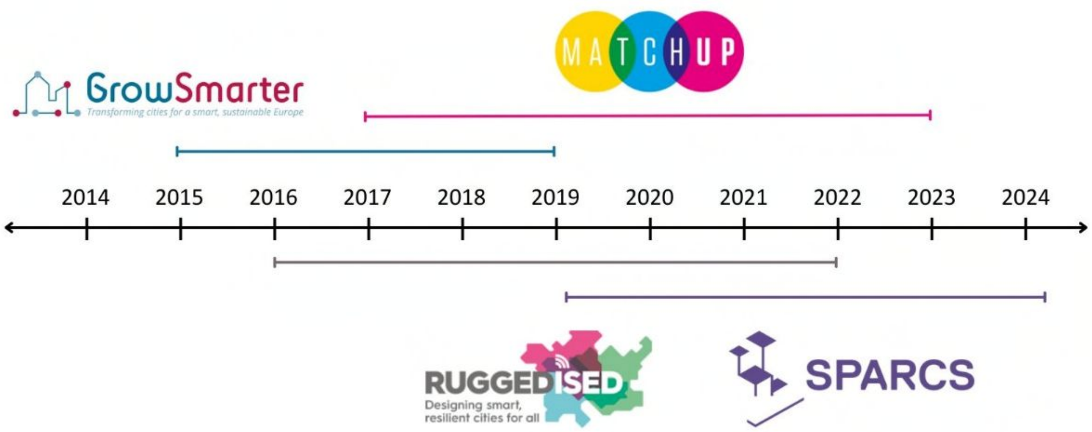

Figure 5. Timeline over the selected projects. Source: Own figure, based on data from European Commission's CORDIS database (n.d).

4.2.2 ICT solution criteria

In this thesis, ICT solutions are defined as technologies that include at least one digital or data-driven component. To be considered as ICT, the solution must go beyond physical infrastructure and incorporate some form of communication, data processing, or control functionality. This means that solutions such as installing PVs, implementing e-mobility vehicles, or retrofitting buildings do not count as ICT solutions, unless the interventions were combined with a digital system that monitored or managed its performance. The solutions assessed here involved at least one of the following technologies: smart sensors, smart meters, smart sockets, data platforms, gamification, IoT devices, energy management systems, virtual power plants, control units, digital twins, dashboards, blockchain technologies, APIs, Big Data analytics, or smart heating systems. The ICT solutions were identified on the project's websites and/or in project documentation. In some cases, solutions were not explicitly labeled as ICT according to the project itself. For example, installing smart controls was listed in one project under energy interventions rather than ICT interventions; that was nonetheless included in this thesis because it met the ICT criteria outlined above. Chapter 5 provides a detailed description of which solutions that were assessed and how they were identified.

4.3 Data collection

A document analysis was chosen as the primary method to gather the empirical data from the selected case studies. The process began with scanning and reviewing each project's official website. On several websites, it was possible to directly identify the project's solutions. However, this information mainly consisted of the name or category of the solutions without further details. To collect further information on each solution, the project's public deliverables and other available material were scanned. Most of the deliverables and reports were collected on the project's website and, when necessary, additional documents were retrieved from CORDIS database (European Commission, n.d-a). That database consists of a brief description of the project, the main results, and links to all public documents and reports. For each project, key documents were collected, including final deliverables, monitoring and evaluation deliverables, factsheets, and best practices summaries. These were selected based on their content regarding the description of ICT solutions. To avoid bias, the ICT selection criteria were developed (chapter 4.2.2).

To manage and structure the collected data, a detailed Excel spreadsheet was developed. The purpose of the spreadsheet was to gather all data in one place to facilitate the data analysis and comparison across the projects. Furthermore, the spreadsheet was developed to align the data with the Multi-Level-Perspective. The spreadsheet included 14 columns:

1. Project
2. City
3. Solution nr
4. ICT category
5. ICT solution
6. Objectives
7. Provisioning system impact
8. Social impact

9. Technical impact
10. Environmental impact
11. Challenges
12. Enabling factors
13. Overall themes
14. Source

The spreadsheet was filled in manually, one solution at the time, after scanning all related documents. Instead of summarizing the solutions in a narrative text, the focus was on extracting concise, relevant insights directly into the spreadsheet. Column 1 “project” included the name of the SCC project, and column 2 “city” stated the name of the Lighthouse City where the ICT solution was piloted. For traceability, column 3 “Solution nr” reflected the solution’s number from each project.

To facilitate data analysis, all 78 solutions were clustered into different ICT categories (column 4). These were: Data platforms, Control systems & energy management, IoT & smart infrastructure, and Advanced modeling & simulation. These categories were developed to enable comparisons across different types of ICT solutions. Each solution was placed in one category based on its primary function, even if it could have fit into multiple categories. For example, if a solution involved both IoT infrastructure and real-time control system, but the focus was on monitoring energy data, it was placed under the category Control system & energy management.

The chosen categories cover all solutions identified. They encompass communication, data processing, and control functionality, which were the criteria for the solutions to be considered as ICT. Furthermore, all technologies mentioned in the ICT solution criteria can be listed under these four categories.

The *Data platforms* category includes ICT systems that collect, integrate, store, or visualize data. This encompasses urban data platforms, open data platforms, API infrastructure, visual dashboards, and mobile applications. In the *Control systems & energy management* category, the ICT solutions are used to monitor and optimize energy. Examples of solutions in this category are energy management systems, demand response systems, and control units for heating/lighting/EV charging. Moreover, *IoT & smart infrastructure* covers the physical ICT installations that enable sensing or monitoring, such as smart meters, smart sensors, smart lightning infrastructure, or smart waste systems. Lastly, the category *Advanced modeling & simulation* included ICT solutions that use data to generate insights or predictions. This category encompasses solutions related to digital twins, AI, or optimization modeling.

Column 5 “ICT solution” provides the specific name of the solution as defined by the project itself. In the “Objectives” (column 6), the main goals of each solution were outlined along with a short description to clarify the solution’s intended function.

To assess the impacts of each ICT solution, the spreadsheet was structured around four dimensions: urban system impact, social impact, technical impact, and environmental impact. When filling in the “Urban system impact” (column 7), the focus was on descriptions of how the solution functionally influenced broader urban systems, for example transportation, energy infrastructure or governance. For the “Social impacts” (column 8), the extracted information was related to how the solution affects citizens, community and governance structures. For instance, it may have raised awareness, improved decision-making progress, or created more job opportunities. In “Technical impact” (column 9), information was collected on what was implemented, the type of technology used, and the resulting performance outcomes. These data were mostly found in technical deliverables where the design of the solution was discussed. Although the environmental impacts are part of the technical assessment, they were separated in the spreadsheet to be able to highlight measurable environmental effects. For “Environmental impacts” (column 10), the documents were scanned for outcomes that reflect how the solutions contributed to environmental sustainability, if mentioned. This included measurable indicators as well as qualitative descriptions found across the documents. In many cases, the environmental impacts were presented through KPIs, for example, % reduction in CO_2 emissions or the amount of energy savings. When specific KPIs were not available, written statements on how the solution was linked to environmental sustainability were also assessed.

For “Challenges” (column 11) the documents were scanned for barriers and challenges related to implementing the solution. In contrast, the focus in column 12 “Enabling factors”, was on conditions and mechanisms that supported successful implementation. In some projects, challenges and enabling factors were stated as separate headlines in documents. Elsewhere, the information was extracted by searching for keywords such as problem, barriers, facilitators, next time, etc.

The purpose of "Overall themes" (column 13) was to identify external macro-level trends or factors that have influenced the implementation of the solution. It was included to simplify capturing the third layer in the MLP-framework, namely landscape pressures. These pressures or developments refer to external influences such as societal, environmental, or economic changes in society. here, the documents were scanned for external trends that were outside the scope of the project but still impacted how or why the solution was implemented. Examples of "Overall themes" ranged from broader concepts such as digitalization and climate change to more specific pressures including municipal climate target regulations, fluctuating energy prices, demand for connectivity, and crises such as the war in Ukraine and the COVID-19 pandemic. The cell was left blank if no underlying theme could be identified.

Column 14 included the sources (single or multiple) from which the information was extracted. Where possible, the corresponding page numbers were also included. All sources can be found in the spreadsheet (Appendix A & G) and are listed in the bibliography. Depending on the amount of data available for each solution, they were assigned a green, yellow, or red label: green when most columns were complete, yellow when the majority were filled, and red when only limited information was available.

4.4 Data analysis

Once all data were collected in the spreadsheet, pivot tables were created to facilitate the analysis. Eight pivot tables were created for each project. The first table illustrates the number of solutions in each ICT category, and the second table lists all the names of the solutions by category. The third, fourth, fifth and sixth tables display the various types of impacts by ICT category. The seventh table highlighted the identified challenges, and the eighth focused on the enabling factors.

The pivot tables simplified summarizing the findings from the projects. All pivot tables are available in the annexes. However, some of the results are only described in the text in the results chapter. For the project crosscutting results, a summary table was created to highlight the most common challenges, enabling factors, and solutions in each ICT category. These were identified through the various pivot tables. When analyzing the landscape pressures, the "overall themes" were grouped into clusters to help organize the results. These were based on column 13, and a separate pivot table highlighted all external themes across all four case studies.

The findings were then analyzed using the second analytical model (Figure 4). The ICT solutions identified were compared to different types of niche innovations based on their characteristics. The impacts were assessed and either analyzed at the niche level in the model or, if they had significant effect on provisioning systems, at the regime level. Challenges identified were analyzed because different types of lock-in mechanisms and the enabling factors were also considered. External trends and overall themes were compared to landscape pressures at the landscape level. Finally, the analytical model helped analyze whether ICT solutions influence socio-technical transitions. A more detailed explanation of the analytical model is described in chapter 3.4, and the analysis itself is presented in chapter 6.

4.5 Method discussion

This thesis uses a qualitative research method based on case studies and document analysis. Such qualitative methods can be criticized for being difficult to replicate. It can also be challenging to draw general conclusions from the empirical data (Bryman & Bell, 2011, p .408). The aim of this thesis, however, is not to make broad generalizations but rather to promote our understanding of the relationship between ICT solutions in smart city projects and socio-technical transitions. Generalization is further discussed in the limitations chapter (Chapter 7.2).

Moreover, the analysis depends on the available data in the publicly accessible project documentation. Not all projects provided the same level of detail, and the descriptions of the various ICT solutions differed across the projects. This affected data consistency and resulted in several data gaps in the spreadsheet. By maintaining transparency in how data was gathered and where, the spreadsheet still allows for an analysis, especially since the objective is to gain broader insights into common impacts, challenges, and enabling factors.

Bryman and Bell (2011, p. 395-399) further highlight the importance of credibility when assessing qualitative studies. Credibility is achieved, among other ways, through detailed descriptions of the research process and consistent objectivity of the researchers. This thesis includes a comprehensive methodology chapter to ensure transparency. Note, however, that categorizing the findings into ICT category, impact category, and other columns involved some level of subjective judgment. Nonetheless, efforts were made to follow the developed and consistent criteria throughout the data collection process to achieve the highest level of objectivity possible.

5. Case studies

A total of 78 project and city-specific solutions were identified and evaluated through the document analysis. The following chapter describes the impacts of ICT solutions across the different projects. It also discusses the common barriers and enabling factors that hinder or facilitate implementation of each solution. Finally, the findings are analyzed through the lens of the MLP framework to examine the extent to which ICT solutions influence broader socio-technical transitions.

5.1 GrowSmarter

5.1.1 Background

GrowSmarter is a closed EU-funded smart city project, part of the program "SOCIETAL CHALLENGES – Secure, clean and efficient energy" (European Commission, 2023). The project started on 1 January 2025 and ran until 31 December 2019. It was one of three projects that received funding from European Commission first call for "Smart Cities and Communities". The total cost of the project was € 35 801 867.83, of which € 24 820 974.38 was funded by the EU (European Commission, 2023). GrowSmarter demonstrated 12 integrated solutions in three Lighthouse Cities: Stockholm, Barcelona, and Cologne. These integrated solutions aimed to solve common urban challenges across the sectors of ICT, mobility, and energy. The three main objectives of the project were to enhance everyday life for citizens, reduce negative environmental impact, and improve sustainable economic development. The demonstration sites at which the solutions were implemented were chosen to reflect different urban typologies. The solutions were demonstrated in downtown city districts, inner city suburbs, and former industrial or business areas that are, or were, partially transitioning to a residential area. The Follower Cities of GrowSmarter were Graz, Porto, Suceava, Cork, and Valetta. During the time of the project, the Follower cities learned from the Lighthouse cities' experiences and developed replication plans adjusted with measures that fit their local context and needs (GrowSmarter, n.d.).

5.1.2 Solutions

The GrowSmarter project collaborated with 25 industrial partners and implemented 12 integrated smart solutions in the three Lighthouse Cities. These solutions are divided into three categories:

Low energy districts, Integrated infrastructures, and Sustainable urban mobility. Each of the 12 solutions consists of specific measures in the form of demonstration actions. Of the 12 integrated solutions, eight involved measures related to ICT and were selected for evaluation in this thesis based on the ICT solution selection criterion mentioned. The eight ICT-related solutions are highlighted with colored backgrounds in Figure 6.

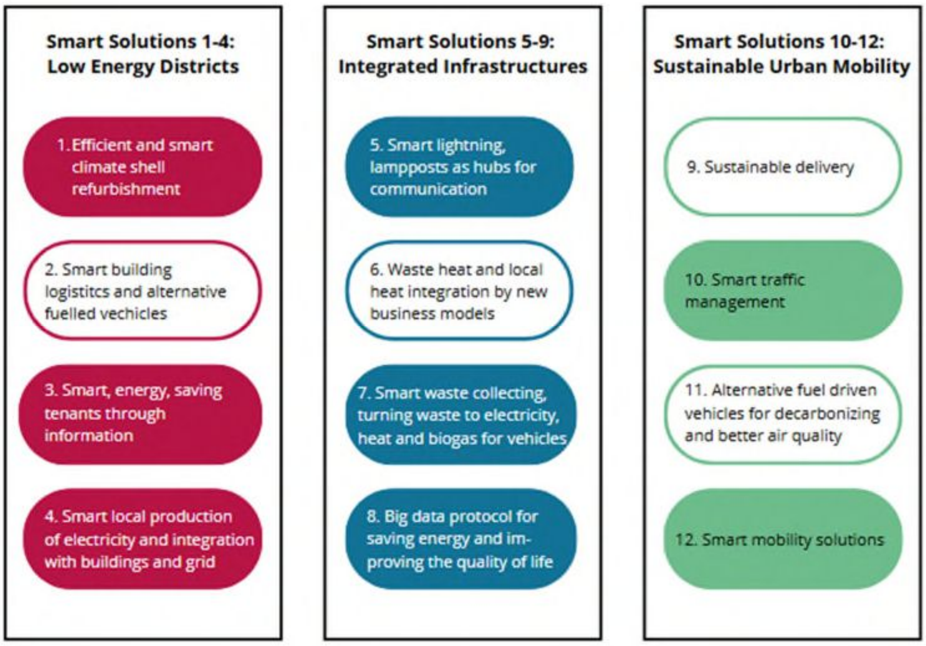

Figure 6. Integrated solutions in GrowSmarter. Source: Own illustration, based on GrowSmarter (n.d)

Within these eight measures, 21 city-specific actions were identified. The identified actions were implemented in all three Lighthouse Cities and covered all four solution categories in this thesis.

Table 3. Count of ICT solutions in GrowSmarter.

Row labels	Count of ICT solution
GrowSmarter	**21**
Advanced modeling & simulation	1
Control system & energy management	8
Data platforms	5
IoT & smart infrastructure	7
MAtchUP	**36**
RUGGEDISED	**11**
SPARCS	**11**
Grand Total	**79**

Source: Own spreadsheet.

The solutions included in this thesis from GrowSmarter are as follows:

Table 4. Solutions in GrowSmarter per category

Advanced modeling & simulation
Urban models and semi-automatic instance mapping
Control system & energy management
HEMS (Home Energy Management System)
Active House – Private home energy management system
Energy management system at neighborhood level
Energy saving center, an IOT platform
EnergyHUB – smart management of photovoltaics and energy storage
Smart home system – private home energy management system
Smart management of photovoltaics and energy storage
Virtual Energy Advisor – open city home energy management system
Data platforms
EcoStruxure Advisor – energy performance evaluation platform for buildings
Integration of sensor and heterogeneous data in standard data format
Open data platform
Open data platform (MetroLIVE App)
Travel demand management app
IoT & smart infrastructure
Adaptive LED lightning
Monitoring of substations and data collection in central platform
Smart connected street environments
Smart meter information analysis and actuators
Smart taxi stand system
SmartTower solution
Waste collection system

Source: Own spreadsheet.

5.1.3 Impacts

Impacts on provisioning systems

In GrowSmarter, many of the solutions impacted the energy domain, which is a central part of provisioning systems. Some ICT solutions helped optimize existing processes, real-time monitoring, and improve system efficiency. Moreover, the impacts of the solutions in the *IoT & smart infrastructure* category showed how sensors and smart meters, among other things, affected traffic systems. This involved reducing traffic congestion, encouraging e-mobility, and improving traffic management, all thanks to collected traffic data. The *IoT & smart infrastructure* solutions also impacted the city's waste system by contributing to more efficient waste management.

Furthermore, one solution impacted emergency services and helped reduce the intervention time in case of emergencies. Other impacts included fewer blackouts, increased connectivity in urban areas, and improved decision-making processes. These improvements were promoted through open data platforms and the access to real-time data. See Appendix B.

Social impacts

Most of the social impacts identified in GrowSmarter were related to improved citizen awareness, engagement, and overall quality of life. For example, one solution related to urban modeling and instance mapping contributed to greater transparency in planning processes, enhanced communication with stakeholders, and raised public awareness. The impact of increased user awareness was identified in several solutions in the *Control systems & energy management* category. By integrating smart monitoring systems into private homes, residents became more aware of their energy use and gained a better understanding of their energy consumption patterns. This encouraged individuals to adjust their energy behavior. Within this category, better decision-making was one repetitive social impact. This reflected the valuable information provided to city planners by deploying sensors. Installing LED lighting improved pedestrian safety and offered job opportunities. Implementing smart waste collection systems led to increased recycling participation, and smart taxi stands reduced unnecessary driving for taxi drivers. See annex B.

Technical and environmental impacts

GrowSmarter showed that ICT solutions improved energy efficiency and data integration. Solutions within the category *Control systems and energy management* provided users with real-time energy-saving tips and enabled remote management of thermostats, lightning, and smart plugs. IoT infrastructure, including sensors from buildings, traffic nodes, and energy systems, was collected in data platforms to support performance tracking. Additionally, a fiber network improved system control and potentially reduced further energy consumption. For the category *Advanced modeling & simulation*, simulation models such as GIS and BIM proved helpful for decision-making. See annex B.

The environmental impacts in GrowSmarter were largely centered on reducing energy consumption and greenhouse gas emissions. Importantly, some solutions stated actual measured impacts in terms of KPIs, while other solutions indicated their impact more broadly. Sometimes, only the potential environmental impact was mentioned. To give one example, the smart home system energy management in Cologne saved 8% energy and yielded a 95 kg reduction of CO_2 emissions per year.

The smart management of photovoltaics and energy storage resulted in increased use of renewable energy sources and reduced greenhouse gas emissions, but no KPIs were provided. In the *Data platform* category, the results showed that open data platforms and travel applications indirectly reduced traffic emissions. This is due to lower vehicle emissions reflecting optimized traffic flow. The sensor-controlled LED lighting led to 31% CO_2 emissions reduction, the self-controlled LED lighting showed 21% savings, and the remotely controlled LED lighting led to 5% savings. Finally, the waste collection solution in Stockholm had environmental impacts, namely a 71% CO_2 reduction, 90% less waste collection traffic, and a 66% reduction in unsorted waste. See Appendix B.

5.1.4 Challenges and enabling factors

When integrating urban models and mapping, the project faced coordination challenges between municipal departments. Ensuring the availability and quality of the data used for these simulations emerged as an additional barrier. One enabling factor identified was the growing demand for data-driven urban planning tools, which encourage and support cities to adopt new technologies.

Within the *Control system & energy management* category, several implemented solutions faced challenges related to user engagement, technological integration, and infrastructural limitations. The results showed that end-users often lacked awareness, trust, and knowledge of energy monitoring technologies. Technical barriers were related to installation complexity, compatibility with existing infrastructure, and data integration issues. In some cases, delays in retrofitting and the inability to monitor energy use at the individual level limited the effectiveness and evaluation of these systems. Moreover, barriers such as data confidentiality restrictions and privacy concerns limited the ability to analyze household energy consumption. Alongside these challenges, several enabling factors were identified that supported implementation. For instance, gamification strategies helped raise user engagement. One active house system gained from integration with larger building operations. In parallel, smart home systems benefited from active communication with tenants, including questionnaires to receive feedback. Favorable regulations from the government and financial support by the municipality also played a role.

Examining challenges within the *IoT & smart infrastructure* category highlighted both technical, economic, and regulatory challenges. High installation and maintenance costs, particularly in technologies such as adaptive lighting and sensor networks, raised concerns about long-term economic viability. Other solutions, such as smart street environments and smart taxi stands, experienced limited user adoption, partly due to a lack of standardization and low perceived value. Privacy concerns and GDPR restrictions also hindered implementing some solutions, for example, installing smart metering and the smart waste collection system. Several enabling factors helped address these barriers. Standardization, both in hardware and permitting, made it easier to implement solutions such as adaptive lighting and camera sensors. Furthermore, cloud-based data hubs were shown to improve sensor data, and it was helpful to take advantage of existing infrastructure, as shown in the Smart Tower solution. Awareness campaigns and asking end-users about their needs were also highlighted as enabling factors in this category.

The *Data platforms* category indicated challenges regarding GDPR restrictions, data provisions, and legal barriers to data sharing. Additionally, a lack of sufficient data quality. Open data initiatives, including the MetroLIVE App, faced barriers related to sensor reliability and prolonged installation processes. The travel demand management app installed in Stockholm had problems with the target group: older citizens may not use smartphones and therefore receive no value from the solution. Importantly, various enabling factors were also identified. EU funding and standardized APIs provided a solid foundation for interoperability. Public-private partnerships and stakeholder engagement were also indicated as enabling factors for data platform solutions. See Appendix B.

5.2 RUGGEDISED

5.2.1 Background

RUGGEDISED is, like GrowSmarter, funded under the European Union's Horizon 2020 research and innovation program (European Commission, 2024). The project is included in the sub-program SOCIETAL CHALLENGES – Secure, clean and efficient energy. The project is categorized in the topic SCC-1-2016-2017 – Smart Cities and Communities Lighthouse project, and the call for proposal is H2020-SCC-2016-2017. RUGGEDISED stands for "Rotterdam, Umea and Glasgow: Generating Exemplar Districts in Sustainable Energy Deployment" (European Commission, 2004).

The RUGGEDISED project included three Lighthouse Cities and three Follower Cities. The Lighthouse cities were Umea, Rotterdam, and Glasgow, and the Follower cities Brno, Parma, and Gdansk. The project aimed to achieve results in several important areas, such as replicability, socioeconomics, environmental sustainability, market transformation, and policy development (RUGGEDISED, n.d.).

5.2.2 Solutions

Over 30 solutions were developed in the Lighthouse Cities throughout the RUGGEDISED project. The solutions were centered on energy transition but include cross-cutting themes (RUGGEDISED, n.d). The project highlights that strong partnerships and collaboration across groups and organizations have been the key lesson learned across all solutions. The solutions in the project were categorized into four different themes: Smart thermal grids, Energy management and connections, Smart electricity grids and E- mobility, and lastly, Urban data platform (RUGGEDISED, n.d). Most solutions related to ICT were identified in the Urban data platform theme, but also in Energy management and connections. 11 solutions were identified as ICT-related and were therefore selected for this impact assessment. The number of the solutions in each category is visualized in Table 5.

Table 5. Count of ICT solutions in RUGGEDISED.

Row labels	Count of ICT solution
GrowSmarter	**21**
MAtchUP	**36**
RUGGEDISED	**11**
Advanced modeling & simulation	1
Control system & energy management	5
Data platforms	4
IoT & smart infrastructure	1
SPARCS	**10**
Grand Total	**78**

Source: Own spreadsheet

The assessed solution names are listed in Table 6.

Table 6. Solutions in RUGGEDISED per category.

RIGGEDISED	
	Advanced modeling & simulation
	3D city operations platform (digital twin)
	Control system & energy management
	Demand-side management in non-domestic buildings
	Energy management system
	Implementation of demand-side management technology in domestic properties
	Smart control of buildings
	Smart peak power control of district heating
	Data platforms
	Digital marketplace for energy (platform)
	Gamification – influence behavioral patterns
	Smart city open-data decision platform
	Smart open-data decision platform and central management system
	IoT & Smart infrastructure
	Climate-smart bus station

Source: Own spreadsheet

5.2.3 Impacts

Impact on provisioning systems

Multiple solutions within *Control system & energy management* led to better control of energy flows in heating, solar, grid and storage systems. Impacts mentioned in the documents were reduced demand by heating networks, supported uptake of renewable energy and grid flexibility. Solutions within *Digital platforms* and *Advanced modeling & simulation* further contributed to more efficient city planning because the solutions helped integrate various sectors such as energy, mobility and infrastructure. Meanwhile, a smart infrastructure solution, namely a smart bus station in Umea, helped shift mobility patterns from cars to public transport. The integration of intelligent control systems in buildings improved the efficiency of heating, cooling and ventilation systems through digital control. See Appendix C.

Social impacts

Implementing demand-side management technology in domestic properties yielded lower energy costs for the citizens. Further monitored impacts included improved comfort and better control over private heating consumption. The integration of data platforms, such as the use of a gamification tool, increased awareness of energy consumption. Open-data platforms also enabled better access to data, both for non-experts and local city planners. Similarly, one 3D city operations platform supported participation among citizens. The climate-smart bus station in Umea received positive user feedback, but since the solution included only one refurbished bus station, it was not possible to measure any behavioral change (e.g. a shift to public transport). See Appendix C.

Technical and environmental impacts

In the *Control system & energy management* category, a key technology used was demand-side management. In non-domestic buildings, building management systems were connected to Siemens DSM controllers via edge routers. In residential buildings, similar technology was installed in over 100 apartments, including a 45KWh battery and integration with grid interface controllers. These solutions enabled a more flexible and efficient use of energy by balancing supply and demand and reducing pressure during peak times. Other tools, such as open-data platforms and central management systems, allowed combinations of different data sets and visualization in real time using APIs and dashboards. Other technical impacts were the integration of sensors.

Of the 11 assessed solutions, only one ICT solution provided concrete environmental impacts in terms of measured KPIs. The smart peak power control of district heating achieved 8% energy savings and lowered peak heat power usage by 21%. Additionally, the solution recorded a reduction of 946 kg of CO_2 emissions. Other solutions within the category *Control system & energy management* reported estimated or potential impacts, such as the potential to reduce energy usage, as well as estimated energy savings and CO_2 reductions. In the *Data platforms* category, the environmental impact was difficult to extract. The platforms supported environmental monitoring, for instance, monitoring of energy, traffic, and air quality, but no specific or numeric impacts were stated. The climate-smart bus station aimed to reduce emissions from car traffic by encouraging public transport, but no KPIs were measured here. The 3D city operations platform supported low-carbon urban planning, but no concrete environmental outcome was mentioned. See Appendix C.

5.2.4 Challenges and enabling factors

In the category *Control system and energy management*, RUGGEDISED faced challenges related to data sharing, configuration issues, and delays. The implementation of demand-side management in non-domestic buildings was delayed due to COVID-19. There were further unclear data sharing agreements between public and private partners which slowed the progress. Identified enabling factors were existing infrastructure, pre-installed devices, and prior business models. Strong collaboration between partners was also seen as an essential enabling factor.

In the *Data platforms* category, challenges included keeping users engaged over time and ensuring usability for non-technical users. There were also difficulties in convincing stakeholders to share data. Other technical challenges occurred when integrating new systems with existing older ones. Municipality support, university involvement and clear data descriptions along with existing city-scale data platforms and accessible interfaces were identified as enabling factors.

For *IoT & smart infrastructure*, the solutions were also impacted by the COVID pandemic, which delayed follow-up activities. Implementing smart control systems in buildings was hindered by system calibration complexity and difficulties integrating technology into older buildings. As in the categories above, the presence of existing smart infrastructure as a baseline was identified as an enabler, along with good cooperation between landowners.

Lastly, the digital twin solution in the *Advanced modeling & simulation* category faced challenges due to a lack of measurable, numerical results, which complicated impact evaluation. Co-creation with the private sector and the possibility to integrate the intervention with other solutions were identified as enabling factors. See Appendix C.

5.3 MAtchUP

5.3.1 Background

The MAtchUP project started on 1 October 2017 and is one of the EU-funded Smart Cities and Communities initiatives under the Horizon 2020 program (European Commission, 2024a) The project aimed to transform cities by implementing innovative and integrated solutions in the energy, mobility and ICT sectors. Furthermore, MAtchUP emphasized developing comprehensive strategies for upscaling and replication. Pilot demonstrations were implemented in the Lighthouse cities Valencia, Dresden, and Antalya, which acted as references for replicability across other European cities, including the Follower cities Herzliya, Kerava, Ostend, and Skopje (MatchUp, n.d.).

5.3.2 Solutions

On the MAtchUP project website, solutions are organized into four thematic areas: Energy, Mobility, ICT and Citizens (SOLUTIONS - MatchUp, n.d.). Each theme included several solution areas, which were further broken down by specific actions in the Lighthouse Cities. While all actions explicitly listed in the ICT area were included in this assessment, ICT components were clearly also embedded in solutions listed under other themes. Therefore, all solution categories on the website were systematically reviewed. Actions aligning with the ICT solution criteria for this thesis were selected and documented in the spreadsheet. In total, actions were collected from six solution groups and three thematic areas, which are highlighted in a colored background in Figure 7.

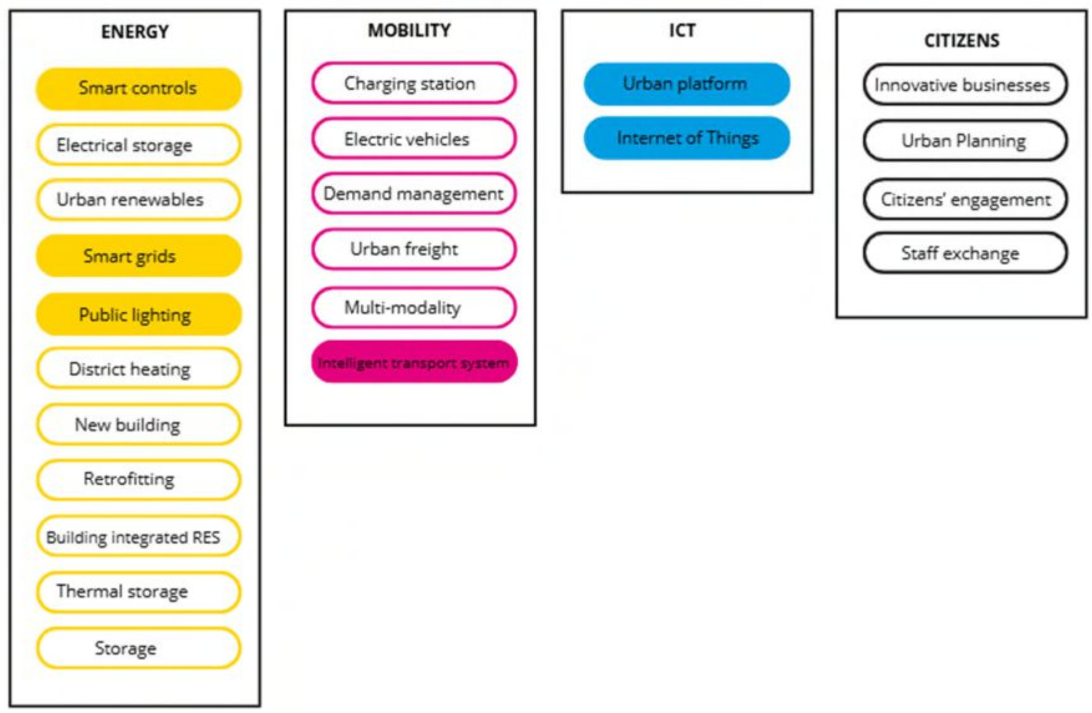

Figure 7. Solution categories in MAtchUp. Source: Own illustration, based on MatchUp (n.d).

A total of 36 city-specific ICT-related actions were identified. Of these, only one solution was marked as green, 11 as yellow, and the remaining 24 as red. This reflects the limited data at the action-specific level. While the MAtchUP project contains several evaluation reports, only a few actions were evaluated individually. 16 of the solutions were identified in the *Data platform* category, 12 were related to *IoT & smart infrastructure,* and eight were placed under *Control system & energy management*. Only one solution matched the criteria for *Advanced modeling & simulation* (Table 7).

Table 7. Count of ICT solutions in MAtchUP.

Row labels	Count of ICT solution
GrowSmarter	**21**
MAtchUP	**36**
Advanced modeling & simulation	1
Control system & energy management	8
Data platforms	16
IoT & smart infrastructure	11
RUGGEDISED	**11**
SPARCS	**10**
Grand Total	**78**

Source: Own spreadsheet

Since several solutions were monitored as one, it made more sense to assess the result on a category level rather than individually. The individual solutions are listed in Table 8. When multiple solutions share similar names, it means that the same or similar solution was implemented in more than one Lighthouse City.

Table 8. Solutions in MAtchUP per category.

Advanced modeling & simulation
Eco-driving patterns to optimize the performance of e-buses
Control system & energy management
Demand management and operation of charging systems for the e-bus fleet
Management of charging systems
Management of e-fleet
Public charging system management
SDEMS – Smart District energy management system
Smart control of public lighting
Smart home energy management system (SHEMS)
Smart management for electromobility
Data platforms
Battery storage platform
Big data functionalities
Citizen's feedback mobility application
IoT and Big Data analysis
IoT data integration with the VLCi smart city platform

IoT urban data platform
Mobility planning application
New open-API developments
New open-data gateway
Open APIs
Open-data management
Urban mobility assistance
Vamos interface for B2B platform
IoT & smart infrastructure
150 smart controls at building level
400 smart meters for building
Demonstration of optimization actions of public lighting
IoT adaptors
IoT adaptors
Management of EV parking places
Smart controls & domotics
Smart lightning 4000 streetlamps and 10 humble lampposts
Smart meter gateway for electromobility
Smart metering deployment
Smart meters

Source: Own spreadsheet

5.3.3 Impacts

The impacts of the ICT solutions in MAtchUP were limited according to the spreadsheet. Grouped impacts of the solutions, however, were explained in the project deliverables. In some deliverables, the actions were evaluated as per all ICT interventions per city. In Antalya, for example, solutions A39-A42 were monitored as one solution. The same indicators were monitored in all three Lighthouse Cities.

The indicators monitored for ICT were improved interoperability, accessibility of open data, increase in online government services, new open-data sets by type of services, provided quality of services through open-APIs, number of users of the app/service and, lastly, numbers of new ISO

KPIs calculated. Where possible, these indicators have been divided into technical, environmental, social, and provisioning systems impact in the spreadsheet. See Appendix A and D.

Impacts on provisioning systems

The solutions in MAtchUP had several impacts on provisioning systems. In the *Control system & energy management* category, solutions enhanced residential energy efficiency, which reduced the overall energy demand. Furthermore, it enabled energy demand response and visual analytics. Within the *Data platform* category, the data collected improved interoperability between various systems. They also impacted the traffic sector by promoting more sustainable ways of travel, reducing traffic jams, and supported intermodal and multimodal mobility coordination. Integrating IoT into data platforms supported long-term city planning and monitoring because data from multiple domains can be used. Smart meters yielded data on energy generation sources and charging stations.

Another impact is the increase in online government services. This is one of the indicators measured at the city level. It measures how many public services are available digitally to citizens and is based on the Likert scale from 1 to 5, assessing how much the project contributed to offering more public, digital services. In Antalya, the value increased from 1.14 to 4.5 during the monitoring period. In Dresden it improved from 2-3.6 and in Antalya from 1-3.9.

The ICT actions in Valencia also contributed to 23 new ISO 137120 KPIs due to improvements in data collection, monitoring tools, and data platforms such as VLCi. These types of KPIs are used by cities globally to measure smart city performance across areas such as mobility, economy, governance and well-being. See annex D.

Technical and environmental impacts

The indicator for improved interoperability measures how the ICT solutions in MAtchUP enhance system interoperability, especially by enabling reusable and interconnected services. This was also measured on a Likert scale from 1 (no improvement) to 5 (excellent improvement), supported by technical data and expert reviews. The interoperability improved in all three cities during the project. In Atalaya, the values went from 1.71 to 3.7, in Dresden from 3.02 to 3.91, and in Valencia from 1 to 3.6. This indicates that, across all Lighthouse cities, the ICT implemented solutions led to a clear technical progress in interoperability. However, the final scores on the Likert scale, ranging from 3-4, indicate only moderate improvement, classified as “somewhat” to “good”. Potential remains for further development and even stronger interoperability.

Another technical indicator measured in MAtchUP was the accessibility of open data, i,e, how easily public data can be accessed and reused based on the 5-point scale. During MAtchUp, Valencia improved from 3.02 to 3.97, whereas the values in both Antalya and Dresden dropped, from 2.98 to 2.11 in Antalya and 3.85 to 3.65 in Dresden.

The implemented ICT solutions also led to new open datasets. The indicator "New open datasets by type of service" monitored the number of newly available public datasets. A total of 340 new datasets were deployed in the three Lighthouse cities during the project. MAtchUP also evaluated the quality of services through open APIs. Here, all cities showed major improvements in service quality and usability. Antalya, Dresden and Valencia all showed scores from 4-5 at the end of the monitoring period. See annex D.

Social impacts

Solutions within the *Control systems & energy management* category increased citizen awareness and engagement in energy saving. A management system also facilitated the work for energy managers and city planners, but no KPIs were monitored. Another social impact collected in the spreadsheet was improved experience in traffic by installing urban mobility assistance. Additional social impacts were improved public access to information, transparency and support in decision-making.

Another social impact measured in the MAtchUp project was the number of users of the implemented service/app. Again, this outcome is not action-specific but general for grouped ICT solutions on a city level. The number of users differed between the cities. Antalya reached 60 users, Dresden had the most (25,000) and Valencia only 32. In Valencia, this indicator is based on the SHEMS and SDEMS applications: these platforms yielded information from the IoT devices deployed during the project. In Dresden, the services with the most users were solution D25, a parking application, and D60, an open data portal. In Antalya, the largest number of users came from the Open Data Portal and Antalya Urban Platform. See annex D.

5.3.4 Challenges and enabling factors

Since multiple solutions in MAtchUP lack individual assessments, the identified challenges and enabling factors are fewer than in other projects. Most challenges were identified in the *Control system & energy management* category. For instance, the SDEMS (a smart district energy management system) faced challenges related to coordination with various city departments. At the same time, its implementation was supported by being integrated into an existing urban platform architecture, in this case, the VLCi platform. The smart home energy management system (SHEMS) faced issues with interoperability, a highly competitive market, and low perceived value and digital engagement among residents. Nonetheless, the findings also indicated several enabling factors that supported this implementation. These included alignment with municipal infrastructure, the ongoing market shift towards more IoT solutions, and the increased interest in energy monitoring due to rising energy costs.

Integrating IoT data into the smart city platform (solution A32) presented challenges, including high development costs, security risks, and the complexity of merging data from diverse devices. The process also depended on existing IoT infrastructure and specific skills in how to turn data into business opportunities. Moreover, there was some citizen reluctance toward monitoring and control. Growing citizen interest in smart solutions and increased demand for data were identified as opportunities for the development of this solution. See Appendix D.

5.4 SPARCS

5.4.1 Background

SPARCS stands for Sustainable energy Positive & zero CARbon CommunitieS and is the last project assessed in this thesis. SPARCS was, like the other Lighthouse projects, funded by the Horizon 2020 project under SOCIETAL CHALLENGES – Secure, clean and efficient energy. The projects ran between 1 October 2019 and 30 September 2024 and had a total cost of 23,785,881 €, whereby the EU contribution was 19,701,216 Euro (European Commission, 2025). The SPARCS project included two Lighthouse Cities and five Follower Cities. The Lighthouse Cities were Espoo in Finland and Leipzig in Germany, while the five Follower Cities were Reykjavik, Kladno, Kifissia, Lviv, and Maia. The project's main goal was to demonstrate how cities can undergo transformation to become more resilient, livable, and sustainable by integrating renewable energy, digital infrastructure, and active citizen participation (Hukkalainen & Kazi, 2024). SPARCS also supported the development of business models and opened new market opportunities for stakeholders engaged in urban transformation. These efforts were meant to transform cities into sustainable, zero-carbon ecosystems while also enhancing the overall quality of life for the residents (SPARCS, n.d.). Beyond implementing interventions, SPARCS also prioritized sharing its results and lessons learned through broad stakeholder engagement, using for instance workshops, publications, and webinars. It also collaborated with aligned initiatives such as Scalable Cities and Mission Innovation (Hukkalainen & Kazi, 2024).

The project engaged 31 partners from 9 EU countries (European Commission, 2025) and included collaborations with companies, research institutes, planning authorities, and citizens (Hukkalainen & Kazi, 2024)

5.4.2 Solutions

In collaboration with project partners, SPARCS implemented around 50 interventions in Espoo and Leipzig. These interventions were monitored and assessed using a set of KPIs designed to capture the interventions' impact. The KPIs are grouped into four categories: energy and environment, economy and innovation, society and quality of life, and governance and replication (SPARCS,n.d).

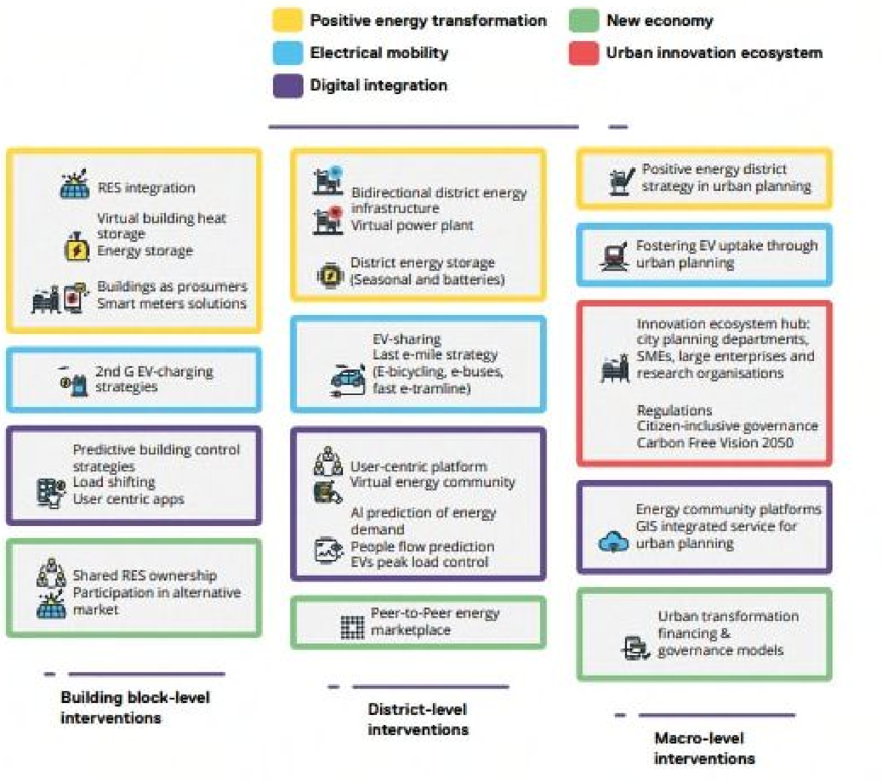

Figure 8. Interventions in SPARCS. Reprinted from SPARCS (n.d)

The interventions are also categorized by their levels of implementation: building block level, district level, and macro level. Within these levels, the SPARCS interventions/actions addressed five thematic solution areas: positive energy transformation, electrical mobility, digital transformation, new economy, and urban innovation ecosystem (Figure 8).

For the present assessment, all ICT interventions in the digital integration are examined together with individual interventions from the *Positive energy transformation* and *New economy* categories. This yielded 10 solutions in total (Table 9).

Table 9. Count of ICT solutions in SPARCS.

Row labels	Count of ICT solution
GrowSmarter	**21**
MAtchUP	**36**
RUGGEDISED	**11**
SPARCS	**10**
Advanced modeling & simulation	1
Control system & energy management	4
Data platforms	3
IoT & smart infrastructure	2
Grand total	**78**

Source: Own spreadsheet

Additionally, the solutions identified in SPARCS are as follows:

Table 10. Solutions in SPARCS per category.

Advanced modeling & simulation
E17: Virtual twin of Sello
Control system & energy management
L11: Leipzig Zero, a smart socket prototype.
E6: ICT for positive energy blocks
L8: ICT integration
E15: VPP solution for public buildings
Data platforms
L12: Human-centric application
L9: Integration of RES
L13: Visual metaphors and dashboards for footprint analysis
IoT & Smart infrastructure
L10: Integration of open standardized sensors and systems.
E16: Smart heating

Source: Own spreadsheet

5.4.3 Impacts

Impacts on provisioning systems

In the category *Advanced modeling & simulation*, which includes SPARCS virtual twin solution E17, the solution affected planning processes and energy performance in buildings. It helped city planners test multiple infrastructure scenarios and optimize layouts for energy efficiency in real urban contexts. The results under the *Control system & energy management* category indicate that smart control systems enabled demand response, for instance via EV charging and VPP integration. Furthermore, the solutions enabled load shifting and integration with district heating systems (E16). In Leipzig, solution L9 supported and improved the transparency of energy generation and consumption across the local grid. The solutions categorized under *Data platforms* demonstrated impacts on data transparency and improved energy efficiency systems. By making real-time energy data accessible through dashboards and applications, these solutions enabled better decision-making and supported more efficient energy use. The implementation of solutions related to *IoT & smart infrastructure* supported smart city architecture across districts. L10, for instance, supported the deployment of a city-wide sensor network. These sensors enabled integrating other smart services such as smart waste management and car parking spot sensors. See annex E.

Technical and environmental impact

The solutions used various technologies during the project's timeline, for instance a smart flexibility platform, predictive energy models, VPP integration, and control-logic for real-time power adjustment in EV charging infrastructure. Additional strategies were integration of smart control of heating systems, peak load management, use of LoRaWan technology, smart meters, smart sockets, and digital platforms.

KPIs were measured per solution and compared to a target. The technical impacts in Espoo and Leipzig were as follows.

Espoo's virtual twin (solution E17) was used to model energy demand and production. It supported over 2000 simulation runs and integrated five technologies for energy forecasting. Solution E6, ICT for PEB, a prediction model using neural networks, was used to forecast energy flexibility. As a result, 27 tons of CO_2 emissions were reduced annually. Smart heating was introduced in over 16,000 apartments or buildings in Espoo using a demand-side management system. In eight monitored buildings, this reduced CO_2 emissions by 13.8 tons per year. In Leipzig the integration of RES (L9) reduced energy generation by 2600 kWh/month and supported the optimization of 411 heating stations using machine learning.

The environmental impact column revealed that some solutions had KPIs describing the environmental impact, while other solutions described potential impacts. The virtual twin improved forecasting accuracy, which can result in energy savings; this, however, was not measured in any numerical results. Solution E6 enabled flexible energy use via smart control and smart EV charging, yielding a reduction of 27 tons of CO_2 per year during the monitored period. That value for E16, as noted above, was 13.82 tons CO_2 across eight buildings. When scaled up, the system could reduce emissions by up to 180 tons annually across the pilot district. Some solutions, such as L8 and L10, had no direct reported environmental impact but were expected to have indirect impacts and reduce emissions by supporting of peak shaving (L8) and resource-efficient urban management (L10).

Social impacts

The ICT-related solutions in SPARCS were shown to increase user awareness and engagement in energy use. Some solutions, such as the virtual twin, also supported strategic planning and city-level simulations. L11-L13 included a smart plug system and a human-centric application and had direct social impacts. The app allowed residents to monitor their energy use, set saving goals and compare consumption with their neighbors. However, due to technical limitations, only 400 out of 1000 planned plugs were deployed, so the actual uptake and behavioral change were limited. No social KPIs were provided for these solutions, but the interventions demonstrated the potential of influencing energy habits. Most of the other solutions had no or limited active citizen participation, and minimal information on solution specific social impacts were communicated in the documents. See Appendix E.

5.4.4 Challenges and enabling factors

In the *Control systems & energy management* category, one key challenge was finding suitable public buildings for implementation, combined with the low financial viability of building-based energy loads. Solution E6 experienced technical barriers when integrating with existing legacy systems. Other technical barriers included issues with Wi-Fi connectivity and socket software. Identified enablers indicated the importance of finding a reliable forecast model and of collaborating with the private sector (e.g. Siemens). Other enablers identified in this category were

EU financing and the use of AI. A third solution in this category, L8 – implementation of a solar thermal plant – could not be completed within the project's timeline due to permit delays and volatility in the energy market, partly influenced by the war in Ukraine.

Within the *Data platform* category, one challenge was maintaining user engagement and ensuring long-term relevance. A key enabler related to this challenge was the development of a user-friendly application.

Under *IoT & smart infrastructure*, limited technical impacts were assessed during the test period. This made it difficult to evaluate its effectiveness. Partnership with housing companies was identified as an enabling factor. See Appendix E.

5.5 Cross-project results

5.5.1 Landscape pressures

Column 13 in the spreadsheet captured external themes, trends, or regulations that potentially influenced the implementation of the solution, based on the public documents. Table 11 clusters these external factors into six groups: *Policy & regulation*, *Digital transformation, Climate & energy transition, Urbanization, Economic pressures,* and *Citizens*. See annex F.

Table 11. Overall themes

Theme	Examples from spreadsheet	Projects affected
Policy & regulation	EU regulations, EU energy efficiency policies, renewable energy acts, climate targets (e.g., Clean Energy Package), GDPR, net-zero goals, legal frameworks	GrowSmarter, RUGGEDISED, SPARCS
Digital transformation	Digitalization, open-data governance, ICT growth, need for interoperable urban data systems, push for open architecture, app-based solutions, demand for data-driven tools, demand for real-time monitoring	All
Climate & energy transition	Energy transition goals, decarbonization targets, climate targets, energy awareness, sustainable development, low-emission priorities, climate change	GrowSmarter, RUGGEDISED, SPARCS
Urbanization	Urbanization, sustainable urban planning, smart mobility, urban infrastructure needs, public-private digital services, mobility demand	GrowSmarter, SPARCS
Economic pressures	Rising energy prices, demand to reduce operational costs, higher implementation costs, market volatility	SPARCS, MatchUP
Citizens	Need for citizen participation, transparency, digital governance, public engagement, awareness in schools/public buildings, safety for citizens	All

Source: Own spreadsheet.

5.5.2 Solutions, impacts, challenges, and enabling factors

Table 12 lists examples of common solutions, challenges, and enabling factors per ICT category. The table is based on the spreadsheet and pivot tables. See Appendix F.

Table 12. Cross-project challenges and enabling factors per category

Category	Example of solutions	Challenges	Enabling factors
Advanced modeling & simulation	Urban models & semi-automatic mapping, digital/virtual twins, 3D city operations platform, eco-driving patterns	Data quality, forecasting accuracy, limited feedback loops	API integration, support from research partners, existing data models
Control systems & energy management	Smart home management systems, district energy management, smart control of public lightning, demand-side management, smart peak power control, ICT for positive energy blocks	Integration with legacy systems, user engagement, coordination complexity, data privacy concerns	Municipal support, EU funding, partnerships with private sector (e.g. Siemens)
Data platforms	Open-data platforms, urban data platforms, energy dashboards, mobility applications, open APIs, gamification tools, digital marketplace for energy	Data standardization, GDPR, maintaining stakeholder engagement	EU open-data policy, user-friendly design, clear data descriptions
IoT & smart infrastructure	Smart meters, climate-smart bus stations, integration of smart streetlamps, sensor networks, IoT adaptors, smart tower, waste collection system	Connectivity issues, high costs, limited test period impact	Modular systems, infrastructure reuse, local partnerships

Source: Own spreadsheet

Table 13 displays a summary of the main impacts on provisioning systems across the four projects. Instead of listing each solution, this table shows the main impacts at category level. The full dataset with impacts from all 78 solutions can be found in Appendix F, Table F4.

Table 13. Cross-project impacts on provisioning systems per category.

ICT Category	Main impacts on provisioning systems
Advanced modeling & simulation	Improved integration of energy, mobility, waste and lighting systems. Supported urban planning processes and helped optimize energy performance in buildings.
Control system & energy management	Enhanced household and building energy efficiency, enabled demand response through EV charging, and integration of renewables, peak shaving and grid flexibility. Enabled citizen engagement through apps and smart home systems.
Data platforms	Improved energy and mobility planning, increased transparency in energy use, enhanced interoperability across services, and supported decentralized energy trading. Promoted governance transparency through open data and improved decision-making.
IoT & smart infrastructure	Enabled smart waste management and smart parking systems. Improved heating efficiency, real-time traffic monitoring, and faster emergency response. Led to energy savings from smart lighting, and supported sustainable mobility

Source: Own spreadsheet.

6. Multi-level perspective analysis

The following chapter studies the findings through the lens of the thesis's second analytical model, which is based on Gees' (2004; 2012; 2019) description of the MLP.

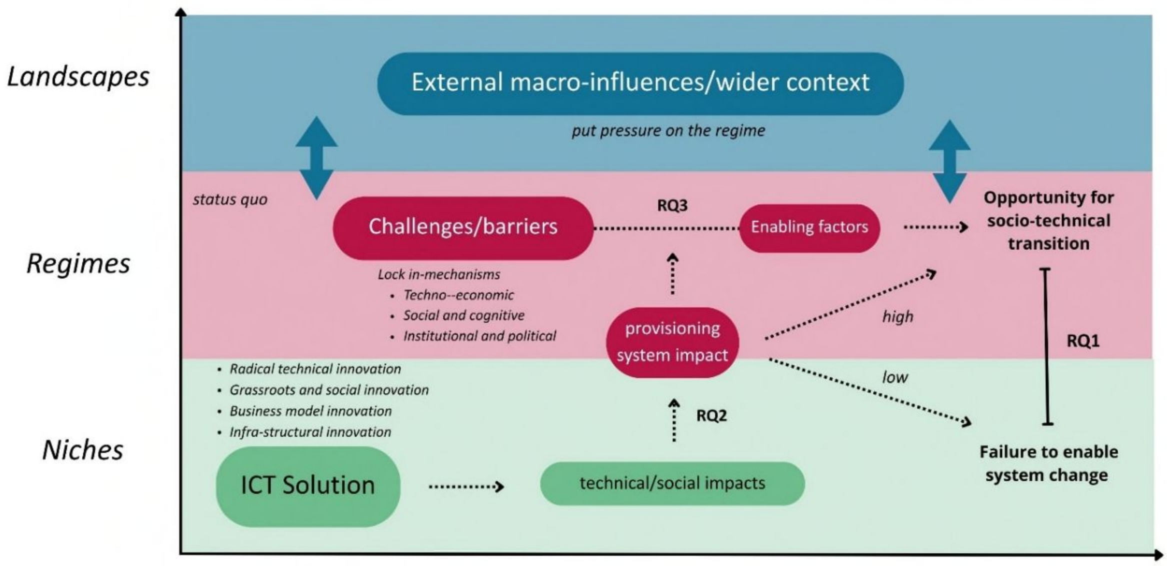

Figure 9. Analytical model, repeated from figure 4. Source: Own illustration.

6.1 Niche level

Within the analytical model, ICT solutions are positioned at the niche level. As described in the theoretical framework, niches are protected spaces where innovations can develop relatively free from the pressures and constraints from existing systems (Geels, 2019). In this case, the smart city projects themselves can be seen as these protected spaces. They provide a structured environment in which the ICT solutions can be implemented and tested without immediate resistance from existing systems. By contrast, if these solutions were introduced outside the scope of a smart city project, they would be more exposed to influences from the dominant regime and perhaps meet more resistance.

Every ICT solution identified in this thesis can be analyzed as an example of niche innovation. In line with Geels (2019), these niche innovations are considered as starting points for transformative change. The ICT solutions can also be distinguished based on different types of niche innovations:

radical technical innovations, grassroots and social innovations, business model innovations, and infrastructural innovations. Most of the identified ICT solutions in here align closest with what Geels (2019) characterized as radical technical innovations. This includes smart energy systems, digital twins, smart sensors etc. Other solutions can be categorized as infrastructural innovations, such as the smart waste management system or the climate-smart bus stop. Moreover, citizen feedback applications and gamification tools can be understood as grassroots and social innovations because they enable greater citizen participation. Finally, services such as digital marketplaces for energy can be viewed as a business model innovation.

In the analytical model, technical and social impacts are placed at the niche level because that is where the niche innovations emerge and where their early impacts become visible. The solutions' impact on provisioning systems, on the other hand, is assessed at the regime level. This is done to determine whether the solutions influence the city's existing systems (regimes) or if the impacts remain limited within the protected niche level. .

6.2 Regime level

The findings revealed that while many solutions somehow influence provisioning systems, the extent to which they do so is mixed. In several cases, such as the virtual twin in SPARCS, there is evidence that the solution was incorporated into city planning routines and resource management, mostly in the energy and mobility domains. Energy management solutions in MAtchUP improved the energy efficiency in residential buildings, which reduced the city's overall energy demand. Additionally, in GrowSmarter, a smart meter solution enabled real-time monitoring of power substations, which reduced emergency intervention time and the frequency of blackouts in the region.

The analysis made evident that most impacts observed in these projects remained on the niche level. Many ICT solutions operated as pilots, experiments, or early-stage implementations and were insufficiently scaled to bring any structural change in the established socio-technical systems (regime). Accordingly, the ICT solutions identified in this thesis appear to coexist alongside existing infrastructures, routines, technologies, behaviors, etc., rather than replace or transform them. This suggests that, for now, the existing technologies continue to be the mainstream, whereas new ICT solutions are being introduced but have not yet altered the overall system.

Lock-in mechanisms

According to the MLP, the regime level is stabilized by various lock-in mechanisms that hinder niche innovations to enter/change the status quo. This thesis operationalizes the lock-in mechanisms in relation to the challenges reported during the implementation of the ICT solutions.

Many of the technical and financial challenges identified, such as data quality problems, high implementation costs, and forecasting accuracy, align well with what Geels (2019) described as techno-economic lock-ins. For example, high implementation costs for a new ICT solution are difficult to justify in existing systems because functional, existing solutions with acceptable performance at a lower cost may already be in place. Those existing solutions have benefited from years of optimization and learning, creating a strong economic incentive to stick with the status quo, especially if the more advanced technology is seen as making only minimal improvement.

Other challenges identified among the ICT solutions were more about people, for example, citizen engagement, coordination complexity, and the difficulties of maintaining stakeholder interest. These challenges can be understood as social and cognitive lock-ins. They arise from habits, routines, and the mindset of those who operate within the regime. For instance, maintaining user engagement proved to be difficult in several projects and across multiple ICT categories. A case in point is implementing data platforms or introducing new energy management systems. Citizens, city planners, or other relevant stakeholders are often accustomed to a standard way of working/living, and shifting to a new system would require altering established workflows and habits as well as learning new skills. For example, limited engagement with smart home management systems may reflect the fact that residents or building owners were already comfortable with their existing routines and saw no reason to invest time in new practices. The reason for few users or low citizen engagement can also be explained by established user practices and lifestyles. For example, the smart bus stop introduced in Umea was designed to encourage a shift from private cars to public transport. However, many residents may have continued to go by car because it is already deeply embedded in their lifestyles.

Another social lock-in is related to the social capital and the established networks and relationships that exist between the stakeholders within the regime. Established partnerships and existing coordination structures made it difficult to coordinate new ways of working. This could help explain problems with the semi-automatic mapping solution in GrowSmarter, which faced coordination issues between municipal departments.

Lastly, Geels (2019) described institutional and political lock-ins. In this thesis, this type of lock-in mechanism can be related to challenges involving regulatory standards and data privacy. One example from the projects is the challenge of data privacy and compliance with regulations such as GDPR, experienced in GrowSmarter. Another example is how projects often had to adapt their solutions to fit different local regulations, data sharing agreements, and administrative procedures. This could slow down both implementation and scaling. In SPARCS, securing municipal approval was complicated due to lengthy decision-making processes.

Enabling factors

The enabling factors this thesis identifies involve elements that help ICT solutions to enter the regime level and overcome barriers, including the lock-in mechanisms.

The key enabling factors identified can also be grouped into institutional, technical, and social domains. Technical enabling factors were interoperability, modular design, open standards, and other solutions that simplified integrating the solution with diverse legacy systems. On the institutional side, strong municipal support, funding, and active partnership with experienced technology providers were identified as enabling factors. Active user engagement and co-design practices can be seen as social enabling factors that are important to overcome social lock-ins.

Overcoming the lock-in mechanisms (or challenges) allows the ICT solutions to move beyond the pilot project and demonstration sites and become better embedded in provisioning systems. In the analytical model the enabling factors are therefore positioned at the regime level. Importantly, enabling factors were also found at the niche level, i.e., enablers solely related to the protected environment. Strong and multiple enabling factors at the niche level boost the chances that the solution will be scaled up, replicated, and then enter the regime. Note also that landscape pressures such as climate change or digitalization can also be understood as enabling factors. In this scenario, enabling factors would therefore be positioned between and across all three levels of the analytical model. The same holds for challenges. They are present at the implementation phase (niche level), in existing systems (regime level), and in external developments (landscape level).

6.3 Landscape level

The landscape level represents broad, external factors that are beyond the control of individual projects or Lighthouse Cities. These forces do not directly influence the specific solution, but they can put pressure on the regime to change or adapt outside of the status quo. The external themes identified in this thesis can be operationalized as broader landscape pressures. Examples are the growing focus on climate change, sustainability, energy efficiency, etc. These central themes have become so significant that cities and communities can no longer ignore them. The urge to solve climate change-related challenges can, for instance, explain the growing attention and funding directed towards smart city initiatives. Strong pressures can destabilize the existing regime, allowing niche innovations to enter and drive system change. Other examples of identified landscape pressures in this thesis are related to policy and regulations, such as EU regulations, renewable energy acts, climate targets, and legal frameworks. They set goals for decarbonization, energy efficiency, and data governance and put pressure on the cities to take action and try to reach these objectives.

Digitalization or digital transformation is another identified landscape trend. The adoption of digital technologies in society is widespread, for example the use of smartphones, AI, and other digital tools. This sets a baseline expectation for solving urban challenges and how to modernize urban infrastructure. Citizens' expectations can also be understood as a landscape pressure. People are demanding more transparency and opportunities for public participation, pressuring cities to implement more open and inclusive approaches. Additionally, economic pressures such as rising prices, higher implementation costs, and market volatility can be understood as landscape pressures in this assessment.

From another perspective, ICT solutions can be analyzed as a trend rather than individual innovations. In this view, it is reasonable to consider that the growing adoption of ICT solutions across various domains is gradually putting pressure on the regime. ICT can therefore be understood as a trend at the landscape level rather than as individual innovations at the niche level. Specifically, as cities start to use ICT more often in different areas such as urban planning, governance, energy, and mobility, these new technologies slowly challenge and put pressure on traditional systems. That said, individual solutions may be insufficient to initiate transitions on their own, but the increasing demand for and integration of ICT could put pressure on the current systems to change.

7. Discussion

7.1 Implications of the findings

One of the unexpected insights from this study was the challenge in understanding how the findings aligned within the different levels of the Multi-Level Perspective (MLP) framework. Before the case study analysis, the assumption was that ICT solutions in smart city projects can be analyzed as niche innovations within the MLP. The ICT solutions were conceptualized as innovations initially introduced within protected spaces such as the smart city project and its demonstration sites. If successful, these innovations gradually shaped and entered existing provisioning systems and their mainstream technologies on the regime level. This proceeded while external factors from the landscape level put pressure on the regime to adapt to these new innovations. However, after reviewing the four SCC projects, it became clear that ICT solutions could also be understood in other ways.

Instead of viewing ICT solutions as individual niche innovations, they can also be understood collectively as part of a broader digital transformation trend. In this sense, ICT can also function as a landscape pressure. For example, the present analysis shows that ICT-driven initiatives are increasingly being driven by EU policies, tech-companies, and public demand. Cities are therefore not merely choosing to invent ICT solutions but are rather being pushed towards them, whether the current system is ready for them or not. Hence, the growing focus on ICT is putting pressure on the regime to make room for new niche innovations. This does not mean that the initial theoretical hypothesis and analytical model are wrong, but it does allow for other possible scenarios. The question arises whether ICT can be both a niche innovation and a landscape pressure. Or if the niche innovations are the specific building stones of ICT (such as smart sensors, smart meters, and software programs), while ICT itself can be analyzed as a landscape pressure. Or if the impact of the solution depends solely on the scale and type of ICT being considered. Measuring the impacts of one solution implemented in one demonstration site in one project may not affect the regime. However, when similar solutions are being tested across multiple projects, the solutions can slowly move up to the regime level and influence socio-technical transitions.

The ICT solutions were not the only ones that were difficult to place in the MLP. At the beginning of this thesis, the challenges related to each ICT solution were conceptualized as lock-in mechanisms positioned at the regime level. However, many of the identified challenges could be linked to each level of the MLP. For instance, challenges can occur in internal project coordination or design (niche level) due to a competitive market, low engagement among residents (regime), or because of broader legal frameworks, norms, and trends (landscape). The same applies when analyzing the enabling factors. A key success factor for an ICT solution to reach the regime level is when a landscape pressure creates a window of opportunity. Other enabling factors are present at the regime level, where they help overcome lock-in mechanisms. Lastly, enabling factors can also be specific to the demonstration site at the niche level. A key takeaway is that the boundaries between the MLP levels are not as clear in practice as they appear in theory. This aligns closely with the critiques of the framework, as discussed in chapter 3.3.4. Genus and Coles (2008), for instance, argued how the levels are difficult to separate empirically, which can create challenges when comparing findings. Genus and Coles (2008) also highlighted the difficulty of defining clear start and end points of transitions, since these often depend on interpretation. This critique was also visible in the analysis. The impacts of the ICT solutions on provisioning systems unfolded unevenly, with no distinct point that could be understood as the start of a transition. This made it difficult to judge whether the observed impacts were substantial enough to result in socio-technical transitions or rather smaller improvements within existing systems.

7.2 Limitations

This thesis focused on four selected SCC projects funded by the European Union under the Horizon 2020 program. The four projects cover different calls, cities, and objectives, but still represent only a part of all closed and ongoing smart city projects. Furthermore, the examined projects are all located within Europe and are a part of the Smart Cities and Communities program. They therefore reflect a similar funding and policy environment. As a result, the findings cannot be automatically generalized to all cities. Cities in regions with lower digital maturity and perhaps limited EU policy alignment may face different impacts, barriers, and enablers when implementing ICT solutions. Therefore, the findings and recommendations in this study are tailored to European Cities with similar conditions. The outcomes and recommendations should be interpreted with caution if applied outside the European context.

This thesis relies on a document analysis of publicly available deliverables from the projects. These documents varied across the projects in terms of data provided, monitoring methods, KPIs, etc.

This inconsistency complicated the comparison between the projects. Furthermore, the data collected here was textual data, often lacking quantitative measures or results. This makes it difficult to rank the solutions based on greatest impact, biggest challenge or similar.

Another related limitation regards project timelines. Many of the implemented ICT solutions were monitored only during a limited period, excluding time to observe long-term impacts or measure whether the initial impacts were sustained. Earlier projects such as GrowSmarter, which ended in 2019, would provide more time for monitoring and follow-up activities compared to more recent projects such as SPARCS, which ended in 2024. However, the follow-up data collection apparently often stopped when the EU funding ended and the project closed. Any impacts after the end of the project were rarely documented or communicated.

Importantly, this thesis did not include any primary data collection. Since the selected smart city projects were closed at the time of the study, many relevant stakeholders were no longer available for interviews, surveys, workshops, or other forms of engagement. Clearly, integrating findings or validating the results based on interviews with project managers, technology partners, or citizens who used the ICT solution in practice would have been interesting. That approach, however, would have been more suitable if the research had focused narrowly on a few selected solutions. That would have made primary data collection through interviews both feasible and relevant, for example, to investigate in-depth best practices of ICT solutions.

Instead, this thesis covers all ICT solutions identified in the four projects, yielding a total of 78 solutions. This broader approach made it possible to analyze general patterns, compare solution categories, as well as identify common barriers and enabling factors. This approach was both appropriate and practical for the scope and timeframe of a master thesis.

Relying solely on project-produced documents includes a risk of reporting bias because these materials are often written to showcase the project's achievements and justify the funding. This potentially involves underreporting of failures, delays, or negative impacts and highlighting successes. This was mitigated here by analyzing from a critical perspective, comparing what the projects initially planned to achieve and the actual results. The findings should, however, be viewed as general patterns rather than definitive proof of impact.

7.3 Future research directions

Future research would benefit from a mixed method approach combining document analysis with in-depth interviews. There is still potential for an in-depth study examining ICT solutions and their impact on provisioning systems.

Future studies should also prioritize exploring case studies beyond Europe and beyond the Horizon 2020 call. This promises to shed light on how similar ICT solutions perform in cities with different governance models, regulatory environments, or socio-economic contexts. A comparative study could examine whether the main technical and social impacts depend on the geographical setting and whether the same enabling factors and barriers apply globally. Another aspect would be determining which local adaptations are necessary to optimize the positive impacts of ICT solutions, and what is needed for successful scaling elsewhere.

Finally, given that limited citizen engagement was identified as one of the most common challenges, future research should investigate more efficient ways to co-develop ICT solutions with end-users and examine what citizens are ready for. This calls for a better understanding of what kind of innovations sustain and impact existing systems. Research in this field would help to bridge the gap between technical feasibility and social acceptance.

8. Conclusion

The objective of this thesis was to examine the extent to which ICT solutions implemented in selected smart city projects contribute to broader socio-technical transitions. The social and technical impacts of various ICT solutions were assessed, as were the barriers and enabling factors encountered during implementation. The case study of four completed SCC projects provided several insights. It contributed with up-to-date insights into the field of smart city development and can help cities understand how to use ICT to become more sustainable. Understanding these impacts is important for solving climate-related challenges and rapid urbanization. Furthermore, this study provided insights into how cities can transition from existing socio-technical systems to new, more sustainable ones.

In response to RQ2 regarding the most common technical and social impacts of ICT solutions in smart city projects, the most reported technical impact was improved monitoring and control of energy. The ICT solutions were shown to enable real-time data collection, predictive modeling, and energy monitoring. Other common technical impacts were enhanced energy efficiency and improved system interoperability. In terms of environmental impacts, the findings indicated that several solutions resulted in energy savings and reduced CO_2 emissions. Nonetheless, many ICT solutions reported only estimated or indirect environmental impacts. From the social dimension, the most common impact was increased user awareness and transparency. Furthermore, some solutions enabled end-users to monitor their own energy use and compare consumption patterns. However, information regarding the extent to which citizen engagement and awareness were reached was limited. The number of users monitored was restricted, and there was no clear evidence of any behavioral shifts. This suggests that while social impacts were present, they tended to remain isolated to a small group of users.

The extent to which ICT solutions are implemented and their resulting impacts depend on the barriers and enabling factors. This was addressed by RQ3: What are the key success factors and barriers when implementing ICT solutions in smart city projects? In line with the thesis's analytical model, the identified challenges were interpreted as lock-in mechanisms at the regime level in the MLP. The findings indicated that the key challenges are related to several types of lock-in mechanisms: techno-economic lock-ins, institutional and political lock-ins, and social lock-ins. The enabling factors could also be grouped into similar categories. Moreover, it was possible to differentiate challenges and enabling factors depending on the ICT solution. The solutions within the *Advanced modeling and simulation* category met mostly techno-economic barriers related to data quality, accuracy, and data availability. Solutions within the *Control systems & energy management* category encountered more institutional barriers such as integration with legacy systems, coordination complexity, and data privacy concerns. Various solutions within the *Data platform* category met regulatory barriers, for example regarding GDPR and data standardization. Enabling factors to solve these issues were, for instance, EU open-data policies. Lastly, the findings in the *IoT & smart infrastructure* category showed how challenges were related to high implementation costs, connectivity issues, and insufficient time for monitoring. These solutions benefited from modular design as well as integration and reuse of existing infrastructure.

These findings helped answer the primary research question: To what extent do ICT solutions, implemented in selected smart city projects, contribute to socio-technical transitions? (RQ1). The analysis showed that such solutions influence socio-technical transitions only to a limited extent. Most ICT solutions had technical and social impacts at the niche level alone, i.e. their effects were constrained to the protected spaces such as the smart city project, its demonstration sites, and a small group of users. While some solutions did show impact on provisioning systems, such as improvement in traffic management and energy efficiency, their overall impact was often restricted by the scale of the implementation. In other words, although ICT solutions demonstrated measurable impacts, the extent was insufficient to change existing socio-technical systems. Nonetheless, the findings do suggest that ICT solutions can be viewed as part of a broader trend of digital transformation in cities (such as landscape pressures) instead of merely individual niche innovations. In conclusion, while the impact of individual solutions on socio-technical transitions was modest, the cumulative effect from many ICT solutions has the potential to shape, change, or influence established systems and contribute to socio-technical transitions over time.

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Appendix

Appendix A - Spreadsheet

The complete spreadsheet contains all data collected for each solution presented in this thesis. All pivot tables included in the analysis were generated from this dataset. Due to its size, the full spreadsheet is provided via a link on Google Sheets. The original spreadsheet was created in Microsoft Excel.

Link to spreadsheet: https://docs.google.com/spreadsheets/d/1__AKJNQd-O0e05vSZMjt_AReUOTVgDrva9pzws-pp4M/edit?usp=sharing

Appendix B – Tables GrowSmarter

Table B1. Impacts on provisioning systems. GrowSmarter.

Advanced modeling & simulation
Urban models and semi-automatic instance mapping
Supported planning
Control system & energy management
HEMS (Home Energy Management System)
18-27% of electricity savings per household (measure combined with retrofitting)
Active House – Private home energy management system
Allowed tenants o monitor and control electricity heating and water via an app.
Energy management system at neighborhood level
Supported a partly self-sufficient energy supply, reduces grid pressure, integrate EV charging to local systems
Energy-saving center, an IOT platform.
Enabled real-time monitoring and optimization of energy in residential and office buildings
Energy HUB – smart management of photovoltaics and energy storage
Improved grid efficiency through peak shaving
Smart home system - private home energy management system
Installed in individual homes and does not impact broader urban systems
Smart management of photovoltaics and energy storage
Improved energy efficiency in buildings
Virtual Energy Advisor – open city home energy management system
Provided real-time electricity consumption insights for users, helping the city collect residual energy profiles
Data platforms
EcoStruxure Advisor – Energy performance evaluation platform for buildings
(blank)
Integration of sensor and heterogeneous data in standard data format
Supports decision-making applications and grant interoperability a standardized management.
Open data platform
Better mobility management
Open data platform (MetroLIVE App)
Use findings to implement other traffic limiting actions. Track vehicle flows. Better decision-making.
Travel demand management app
Supports sustainable urban mobility.
IoT & smart infrastructure
Adaptive LED lightning
Several lightning technologies tested, reduced energy
Monitoring of substations and data collection in central platform
Reduced intervention time in case of emergency. Fewer blackouts, fewer managements costs
Smart connected street environments

Integrated multiple sensors into urban infrastructure to collect traffic and pedestrian data, improves traffic management
Smart meter information analysis and actuators
Tenants can optimize their energy consumption, which lead to energy savings
Smart taxi stand system
Reduction in traffic congestion, potential integration with MaaS platforms
SmartTower solution
More connectivity in the urban area. Provides real time info about the city
Waste collection system
Improved waste management

Table B2. Social impacts. GrowSmarter.

Advanced modeling & simulation
Improved transparency and stakeholder communication, better citizens' awareness
Control system & energy management
Gave tenants (over 400 users) energy-saving recommendations via an app. Raises awareness.
Improved ease of heating and better understanding of energy consumption
Promotes citizen participation in energy management
Raised awareness of energy use and helped residents adjust consumption behavior
Reduced privacy concerns compared to home-level monitoring, better energy control for building owners. Helps decision-making processes
User awareness and appliance specific control via app
(blank)
Data platforms
Assist citizens to avoid congestion. Increased transparency, better citizen navigation
Engaged individual users.
Enhances user experience, improved access to mobility data
Raised awareness on energy impacts
Supports decision making
IoT & smart infrastructure
Better quality of life, increased recycling participation
Helping city managers in decision-making. Resolve the wireless connectivity demand which enhance daily life for citizens. 2200 users per month
Offer job opportunities. Citizen’s safety (more lights when they are passing)
Provide better insights for city planners, decision making, however, limited direct interaction with the public
Reduction in unnecessary driving for taxi-drivers, public habits did not change much
Residents can monitor their energy use (awareness, save costs, etc.). Enables decision-making

Table B3. Technical impacts. GrowSmarter.
Advanced modeling & simulation

GIS, BIM and energy simulation models could help enhance decision making.
Control system & energy management
AI-based analysis provided personalized saving tips. Allowed users to compare consumption over time. Integrated with municipality policies
AI-based analysis disaggregated energy consumption. Smart thermostat and plugs enabled automated energy adjustment. Integration with photovoltaic generation data
Controls 63 energy systems using 6000 data points every 15 minutes and forecasts energy performance 36 hours ahead
Developed a software that can optimize performance of the system (emissions, costs, usage of renewables). Inputs such as electricity prices forecast, weather forecast affecting energy production etc.
Enabled remote control of lights and thermostats. Connection to a smart hub for real-time energy tracking
EnergyHUB converts electric current from DC to AC and AC to DC. Installation of a management software in different kinds of buildings. Provide useful information for installing PV where they can deliver optimal results
Installation of thermostats, smart plugs, sensors and an app-based device for control. Open APIs for data integration.
Integration with existing building control systems and IoT sensors. Collected live data from district heating, water and electricity networks
Data platforms
Cloud-based IoT platforms that aggregates building data and evaluate KPIs
Developing of an app integrating GPS and travel data
Enable real-time integration of multiple data sources to improve awareness
Real-time data processing, compliance with EU open urban data standards. Integrated 13 urban data sources
(blank)
IoT & smart infrastructure
5 substations were monitored, data were collected in a central platform.
55 GM per month
Camera-based sensors could provide accurate traffic and environmental data. Data were fed into an IoT platform for analysis
Deployment of 3 technologies
Fiber network for improved system control, potential for further energy consumption reduction when system upgrades
Installed sensors at three taxi stands, enabled data transfer and display in an application
Smart plugs were deployed as part of the SmartHome system. Web-based energy dashboard to visualize own and others energy use.

Table B4. Environmental impacts. GrowSmarter.

GrowSmarter
Advanced modeling & simulation
Potential for reduced emissions and more efficient energy use
Control system & energy management

(estimated) reduce carbon emissions and improves air quality
15% reduction in household electricity use
8% of energy savings, 95 Kg reduction in CO2 emissions per year
Electricity saved
Helped optimize household energy use, energy savings in refurbished buildings
Increased use of renewable energy sources reduces greenhouse gas emissions
Reduce heating, electricity and water use
Reduced demand peaks that stress the grid. More usage of sustainable electricity from EnergyHub
Data platforms
CO_2 emission reduction (5%)
Indirect reduction in traffic emissions
Indented to reduce carbon emissions of mobility
Reduce emissions/track emission impact. Lower vehicle emissions due to optimized traffic flow
(blank)
IoT & smart infrastructure
71% CO_2 reduction, 90% less waste collection traffic, 66% reduction in unsorted waste
Estimated to support emission reduction by optimizing traffic flow
Estimated 15% energy savings through behavior change
Estimated impact: Up to 50% reduction in CO_2 emissions if all taxis use stands. Also, up to 50% reduction in kilometers driven (OBS estimated)
The sensor-controlled LED lightning: 31% reduction is CO_2 emissions. The self-controlled LED street lightning: 21 % savings. The remotely controlled LED street lightning: 25% savings

Table B5: Challenges per category and solution. GrowSmarter.

Advanced modeling & simulation
Urban models and semi-automatic instance mapping
Coordination challenges between municipal departments. Ensuring data availability
Control system & energy management
HEMS (Home Energy Management System)
Lack of awareness. Mistrust of the importance of energy consumption monitoring. End-user challenges regarding the tenants' lack of tech knowledge
Active House – Private home energy management system
Required tenant education and engagement for effective use, installation complexity. Improving battery life presents a challenge: the longer they last the more convenient
Energy management system at neighborhood level
Connecting and controlling power systems to a new external control. Time consuming to collect software and equipment requirements, retrofitting delays can affect implementation. Impossible to monitor electricity consumption at individual dwelling level.

Energy saving center, an IOT platform
Network security challenges, challenges with coordination between multiple building owners and data access limitations.
EnergyHUB – smart management of photovoltaics and energy storage
.
Smart home system – private home energy management system
Trust and privacy concerns, hesitancy towards uncertified meters. Citizens not familiar with the technology. Sensitive economic feasibility
Smart management of photovoltaics and energy storage
Large datasets, technical challenges regarding integrating the system (depending on the battery inverter manufacturer).
Virtual Energy Advisor – open city home energy management system
Data confidentiality restrictions, which limited the ability to fully analyze individual household consumption.
Data platforms
EcoStruxure Advisor – Energy performance evaluation platform for buildings
GDPR compliance, data quality responsibility, timing of data gathering added costs and complexity.
Integration of sensor and heterogeneous data in standard data format
Having enough data to fill the platform with
Open data platform
Concerns about data provision. Legal barriers to data sharing
Open data platform (MetroLIVE App)
Main challenges are around sensor technology and the data quality from the sensors Time consuming to implement new sensors. Uncertainty how to differentiate bicyclists from pedestrians
Travel demand management app
Challenging target groups (older people may not have smartphones). Technical challenges related to the GPS function, which consumed a lot of battery power from the phones. Unclear long-term user adoption, underestimated development costs
IoT & smart infrastructure
Adaptive LED lightning
Not economically sustainable in Sweden due to low electricity prices, long pay-back time. Maintenance of these smart lights could be challenging with evolving technologies
Monitoring of substations and data collection in central platform
Large number of sensors were needed to see more impact on a larger scale
Smart connected street environments
Technical limitations of Wi-Fi based sensors, high initial costs, lack of standardized sensor protocols. Few users and little added value
Smart meter information analysis and actuators
Tenants' participation due to privacy, certification concerns, engagement difficulty
Smart taxi stand system
High costs of network access, system use, and issues related to data costs were long-term challenging. Lack of regulations forcing taxis to use stands. Consumers prefer to be picked up at their specific location rather than at taxi stands. Challenging to monitor and evaluate results
SmartTower solution

(blank)
Waste collection system
GDPR restrictions on waste data, tenant consent issues, higher than expected energy consumption

Table B6: Enabling factors per category and solution. GrowSmarter

GrowSmarter
Advanced modeling & simulation
Urban models and semi-automatic instance mapping
Growing demand for data-driven urban planning tools
Control system & energy management
HEMS (Home Energy Management System)
Use gamification. Integrate in new construction projects
Active House – Private home energy management system
Integrated with building energy retrofits, gained interest from major building operations
Energy management system at neighborhood level
(blank)
Energy saving center, an IOT platform
From factsheet: Developing the business model from B2C (Business-to-Consumer) to B2B (Business to-Business) could be a good opportunity to upscale the solution
EnergyHUB – smart management of photovoltaics and energy storage
Need to lower peak loads. Measure the solutions in different kind of buildings
Smart home system - private home energy management system
Have a questionnaire follow-up, asking for feedback from the tenants. Good communication
Smart management of photovoltaics and energy storage
Favorable regulations from the government (such as RD244 in Spain), e.g. exemptions applied by municipalities. Public incentives for battery adoption
Virtual Energy Advisor – open city home energy management system
Funding by the municipality, part of campaign "Take Charge of Your Energy"
Data platforms
EcoStruxure Advisor – Energy performance evaluation platform for buildings
(blank)
Integration of sensor and heterogeneous data in standard data format
(blank)
Open data platform
EU funding support, standardized APIs, public private partnership
Open data platform (MetroLIVE App)
Strong municipal ICT strategy, open data polices
Travel demand management app
Stakeholder engagement, clear visual identity
IoT & smart infrastructure

Adaptive LED lightning
Standardization could help speed up permitting or reduce prices. Feeling of safety is important
Monitoring of substations and data collection in central platform
Cloud-based data hubs.
Smart connected street environments
Standardization of camera-based sensors improved feasibility, data were useful for multiple stakeholders. Ask the end-users for their needs instead of just putting up sensors in an area and hope for application potential. Economic feasibility in the long term
Smart meter information analysis and actuators
Leveraging existing SmartHome users.
Smart taxi stand system
(blank)
SmartTower solution
Use existing lightning infrastructure
Waste collection system
Awareness campaigns for the resident's participation, potential system upgrades for energy efficiency

Appendix C – Tables RUGGEDISED

Table C1. Impacts on provisioning systems. RUGGEDISED.

Advanced modeling & simulation
3D city operations platform (digital twin)
Improved integration of energy, mobility, waste and lightning systems. Enhances planning efficiency
Control system & energy management
Demand-side management in non-domestic buildings
Increased grid flexibility, enabled smart control of commercial energy loads
Energy management system
Enables integrated control of heating, solar, grid and storage systems
Implementation of demand-side management technology in domestic properties
Support uptake of renewable energies and grid flexibility. Allow citizens to feel benefit of a micro-grid system
Smart control of buildings
Improved efficiency of heating, cooling and ventilation through digital control
Smart peak power control of district heating
Reduced demand on district heating networks. District heating providers can avoid the use of peak loads unit and therefore save money and reduce negative climate impact at city-level
Data platforms
Digital Marketplace for Energy (platform)
Support decentralized energy trading models.
Gamification – influence behavioral patterns
Energy efficiency in public buildings
Smart city open-data decision platform
Enhanced planning. Support energy, mobility and urban services
Smart open data decision platform and central management system
Improve city planning, support smart energy, mobility and environmental management
IoT & smart infrastructure
Climate-smart bus station
Supports shift from car use to public transport

Table C2. Social impacts. RUGGEDISED.

Advanced modeling & simulation
3D city operations platform (digital twin)
Open access to data. Support participation
Control system & energy management

Demand-side management in non-domestic buildings
(blank)
Energy management system
Raised awareness of energy-natural operation among stakeholders
Implementation of demand-side management technology in domestic properties
Lower resident energy costs, improved comfort, better control over private heating
Smart control of buildings
Energy awareness. Indoor comfort
Smart peak power control of district heating
Users maintain indoor comfort and do not notice any differences.
Data platforms
Digital Marketplace for Energy (platform)
(blank)
Gamification – influence behavioral patterns
increase awareness of energy use.
Smart city open-data decision platform
Open access to data for citizens. Simplifies engagement in local planning
Smart open-data decision platform and central management system
Broader access to data, accessible also for non-experts
IoT & smart infrastructure
Climate-smart bus station
Positive user feedback, promotes more people to use sustainable mobility, behavioral change

Table C3. Technical impacts. RUGGEDISED.

Advanced modeling & simulation
3D city operations platform (digital twin)
Integrated open standards, real-time data visualization, ICT platform.
Control system & energy management
Demand-side management in non-domestic buildings
Connected BMS to Siemens DSM controller via IoT Edge Router, the integration was tested across mixed energy loads
Energy management system
Platform that aggregates real-time data from various sources. Applies smart control to balance energy supply and demand.
Implementation of demand-side management technology in domestic properties
Installed "connected response" in over 100 flats, 45KWH battery, integrated with Siemens Grid Interface controller
Smart control of buildings
Sensors and control systems using real-time data and automation. Integration with solar PV and storage
Smart peak power control of district heating

Using AI, weather forecasting, smart sensors, thermal energy storage in buildings and control units for heat distribution
Data platforms
Digital Marketplace for Energy (platform)
Development of a platform that allows dynamic pricing and exchange of local energy surplus.
Gamification – influence behavioral patterns
interactive dashboard which can display real-time energy data, not directly linked to control systems
Smart city open-data decision platform
Open data platform with API access, real-time data visualizations. Dataset combination capabilities
Smart open data decision platform and central management system
Integrate datasets using APIs and visual tools
IoT & smart infrastructure
Climate-smart bus station
Implemented real-time GPS linked lightning and sounding systems, routable pod seating for microclimates

Table C4. Environmental impacts. RUGGEDISED.

Advanced modeling & simulation
3D city operations platform (digital twin)
Supports low carbon urban planning
Control system & energy management
Demand-side management in non-domestic buildings
Potential to reduce peak energy usage and emissions. No data
Energy management system
Estimated 383 MWh/year and 155 tons CO_2/year – the actual impact was based on stakeholder interviews, not system monitoring
Implementation of demand-side management technology in domestic properties
Support grid balancing and increase use of renewable energy by shifting domestic demand. Reduce energy use by 30%
smart control of buildings
Reduced energy, lowered CO_2 emissions, solar generation more effectively used
Smart peak power control of district heating
8% of energy savings and shave peaks with up to 21% in peak heat power usage. Reduction of 946 kg of CO_2 emissions during the pilot
Data platforms
Digital Marketplace for Energy (platform)
(blank)
Gamification - influence behavioral patterns
(blank)
Smart city open-data decision platform
Supports environmental monitoring.

Smart open-data decision platform and central management system	
	Monitoring of energy, traffic, air quality
IoT & smart infrastructure	
Climate-smart bus station	
	By encouraging public transport the aim is to reduce emissions from car traffic

Table C5. Challenges per category and solution. RUGGEDISED.

Advanced modeling & simulation		
	3D city operations platform (digital twin)	
		No numerical results – difficult to measure impact. Data ownership, standardization, vendor lock-in, governance issues
Control system & energy management		
	Demand-side management in non-domestic buildings	
		Covid 19 delays, configuration issues
	Energy management system	
		Unclear data-sharing agreements between public and private partners.
	Implementation of demand-side management technology in domestic properties	
		Battery fire safety, delays, electrical issues in battery location
	Smart control of buildings	
		System calibration complexity, integration into older buildings
	Smart peak power control of district heating	
		The weather variation affected the predictability, differences in building thermal mass
Data platforms		
	Digital Marketplace for Energy (platform)	
		(blank)
	Gamification – influence behavioral patterns	
		User engagement and relevance over time.
	Smart city open-data decision platform	
		Data standardization, stakeholder engagement (convince stakeholder to publish data)
	Smart open-data decision platform and central management system	
		Technical integration with legacy systems, ensuring usability for non-technical users
IoT & smart infrastructure		
	Climate-smart bus station	
		Design complexity, pandemic impacted follow-up of the solution

Table C6. Enabling factors per category and solution. RUGGEDISED.

Advanced modeling & simulation		
	3D city operations platform (digital twin)	
		Information. Co-creation with private sector. Integration with other solutions (R8)
Control system & energy management		

Demand-side management in non-domestic buildings
Pre-installed eMic devices, existing BMS infrastructure
Energy management system
existing infrastructure, multiparter collaboration. Open ICT platform
Implementation of demand-side management technology in domestic properties
Partnership with Wheatley Group, smart grid integration
Smart control of buildings
Cooperation from property owners and smart infrastructure baseline
Smart peak power control of district heating
Existing district heating infrastructure, prior business models
Data platforms
Digital Marketplace for Energy (platform)
(blank)
Gamification – influence behavioral patterns
Accessible interfaces and integration with building data systems
Smart city open-data decision platform
University engagement, municipal policies, clear data descriptions
Smart open-data decision platform and central management system
Already existing city-scale data platforms, commitment from governance
IoT & smart infrastructure
Climate-smart bus station
Cooperation between multiple landowners

Appendix D – Tables MAtchUP

Table D1. Impacts on provisioning systems. MAtchUP

Advanced modeling & simulation
(blank)
Control system & energy management
Enables energy demand response and visual analytics
Enhances residential energy efficiency, reduces overall energy demand, link with city-level data
(blank)
Data platforms
Data will impact strategic decisions of the city's mobility improvement areas
Facilitate the integration of new services into VLCi platform. Interoperability
Increase in online government services from 1/5 to 4.5/5. Improved interoperability from 1/5 to 3.7/5.
Promote sustainable ways of transport
Reduce traffic jams/improve commuter experience through early alerts
Support city monitoring and long-term planning by consolidating data from multiple urban domains. The datasets are connected to smart meters in residential and public buildings, energy generation, e-mobility and charging stations (handbook, p. 12)
Supports city planning and performance tracking D2.21, p26 & section 8
Supports third-part innovation and city service integration
Supports intermodal and multimodal mobility coordination
Supports open governance and other smart city services through public data
(blank)
IoT & smart infrastructure
(blank)

Table D2. Social impacts. MAtchUP.

Advanced Modeling & Simulation
(blank)
Control System & Energy Management
Decision-making for energy managers and city planners.
Increases citizen awareness and engagement in energy saving. Users can manage invoices, home and device settings through app. Gamification
(blank)
Data Platforms
(estimated) improves citizens experience in traffic
60 users at the end of the monitoring period. Increase and then decrease in accessibility of open data.
Enables citizens to access data. Transparency, help in decision-making
Facilitate and encourage innovation and development of new apps or solutions that improve the city
Foster new businesses, entrepreneurs and SME, start-ups
Improved public access to information, awareness
(blank)

IoT & Smart Infrastructure
(blank)

Table D3. Technical impacts. MAtchUP.

Advanced Modeling & Simulation
(blank)
Control System & Energy Management
Integration of smart meters, sensors for gas, electricity temperature
Remote monitoring of charging station status and integration with urban data platform
Smart meters, energy tracking tools, integration with VLCi platform
(blank)
Data Platforms
62 new open-data sets at the end of monitoring period
Based on so-called CKAN platform and complies with DCAT-AP standard (D2.21, p. 23)
Built on Power BI, Node-RED, Hadoop and other visualization tools for Big Data analysis. p. 50
Development of UDP where all data from the city council systems and other systems are open for citizens and policy makers
Implementation of central database, development of app, integration of app into theme city map
Use NGSI, CKAN, RTOD, Geo APIs etc.
(blank)
IoT & Smart Infrastructure
(blank)

Table D4. Environmental impact. MAtchUP.

Advanced Modeling & Simulation
(blank)
Control System & Energy Management
Reduction in household energy consumption, leading to decreased carbon emissions. 27% reduction in electricity in the testing building (private home, 4 residents) D5.5 p. 37.
(blank)
Data Platforms
(estimated) reduced car emissions
Contributes indirectly by informing energy and environmental decision-making
(blank)
IoT & Smart Infrastructure
(blank)

Table D5. Challenges per category and solution. MAtchUP.

Advanced Modeling & Simulation

(blank)
Control System & Energy Management
10 e-buses were bought but due to the timeline of the project they have not been monitored.
Interoperability issues. Highly competitive market. Low value and digital engagement among residents
Requires coordination with city departments and adapting planning needs
(blank)
Data Platforms
4 ICT actions monitored as one
4 ICT actions monitored as one
High development costs. IoT security risks. Complexity in integrating data from various devices. Dependence on existing IoT devices. Skills to leverage the data for new business development. Reluctance of citizens towards monitoring and control (handbook p. 13)
(blank)
IoT & Smart Infrastructure
4 ICT actions monitored as one
(blank)

Table D6: Enabling factors per category and solution. MAtchUP.

Advanced Modeling & Simulation
(blank)
Control System & Energy Management
Being embedded in VLCi urban platform architecture
Developed in coordination with municipal infrastructure. Market focused on IoT. Higher energy costs makes people interested in monitoring their energy consumption
(blank)
Data Platforms
Cloud bases, modular
Financed by municipal funds. p. 159
Increasing interest among citizens in smart solutions. Growing demand for data usage in specific applications (handbook, p. 13)
Strong municipal open data policy and technical support for CKAN
The city platform supports documentation and testing endpoints
(blank)
IoT & Smart Infrastructure
(blank)

Table D7. ICT indicators impact Antalya. Source: MAtch UP Technical Evaluation D5.5.

Indicator	Monitoring period	Monthly indicator values (reported every 6 months)	Observed change
I6) Number of users of the app/service	Jun 2022 (M57) – May 2023 (M68)	m44: 30 m50: 40 m56: 47 m62: 52 m68: 60	60 users at the end of the monitoring period
I1) Improved interoperability	Jun 2022 (M57) – May 2023 (M68)	Baseline m30 Mar 2020: 1 m44: 1,71 m50: 1,8 m56: 2,3 m62: 2,98 m68: 3,7	The interoperability improved from 1/5 to 3,7/5.
I2) Accessibility of open data	Jun 2022 (M57) – May 2023 (M68)	Baseline m30 Mar 2020: 1 m44: 2,98 m50: 2,16 m56: 2,12 m62: 2,11 m68: 2,11	The average rating of the open datasets on the Berners-Lee 5-star scale improved from 1 to 2,98, and then decreased to 2,11.
I3) Increase in online government services	Jun 2022 (M57) – May 2023 (M68)	Baseline m30 Mar 2020: 1 m44: 1,14 m50: 2,25 m56: 3,13	The access the online services constantly improved from baseline (1/5) and

		m62: 3,75 m68: 4,5	during the monitoring period and was excellent (4,5/5) at the end of the monitoring period.
I5) Quality of services through open APIs provided	Jun 2022 (M57) – May 2023 (M68)	m44: 1 m50: 1 m56: 1,67 m62: 3,08 m68: 4,42	The quality of services through open APIs constantly improved during the monitoring period and was good (4,42/5) at the end of the monitoring period.
I4) New open data sets by type of services	Jun 2022 (M57) – May 2023 (M68)	Baseline m30 Mar 2020: 0 m44: 52 m50: 52 m56: 54 m62: 57 m68: 62	62 new open data sets at the end of the monitoring period

Table D8. ICT indicators impact Dresden. Source: Match UP Technical Evaluation D5.5

Indicator	Monitoring period	Monthly indicator values (reported every 6 months)	Observed change
I5) Quality of services through open APIs provided	Apr 2020 (M31) - Mar 2022 (M54)	Baseline (m30): 3,21 m36: 3,27 m42: 4,51 m48: 4,51 m54: 4,51	The quality of services through open APIs improved from 3,21/5 to 4,51/5.
I1) Improved interoperability	Apr 2020 (M31) - Mar 2022 (M54)	Baseline (m30): 3,02 m36: 3,15 m42: 3,79 m48: 3,87 m54: 3,91	The interoperability improved from 3.02/5 to 3,91/5.
I2) Accessibility of open data	Apr 2020 (M31) - Mar 2022 (M54)	Baseline (m30): 3,85 m36: 3,85 m42: 3,65 m48: 3,65 m54: 3,65	The average rating of the open datasets on the Berners-Lee 5-star scale decreased from 3,85 to 3,65.
I3) Increase in online government services	Apr 2020 (M31) - Mar 2022 (M54)	Baseline (m30): 2 m36: 2,33 m42: 3,22 m48: 3,44 m54: 3,56	The access to online services constantly improved from the baseline (2/5) during the monitoring period and was good (3,56/5) at the end of the monitoring period.
I4) New open data sets by type of services	Apr 2020 (M31) - Mar 2022 (M54)	Baseline (m30): 893 open datasets in the platform m36: 986 m42: 986 m48: 986 m54: 1028	The number of open data sets increased from 893 to 1028.
I6) Number of users of the app/service	Apr 2020 (M31) - Mar 2022 (M54)	m31: 6653 m36: 17 116	The number of users peaked in October 2021

		m42: 13 108 m48: 23 169 m54: 15 944	(25156 users) and was 15 944 at the end of the monitoring period.

Table D9. ICT indicators impact Valencia. Source: Match UP Technical Evaluation D5.5

Indicator	Monitoring period	Monthly indicator values (reported every 6 months)	Observed change
I6) Number of users of the app/service	Apr 2020 (M31) – Mar 2023 (M66)	m36: 0 m42: 0 m48: 3 m54: 27 m60: 30 m66: 32	32 users at the end of the monitoring period
I1) Improved interoperability	Apr 2020 (M31) – Mar 2023 (M66)	m36: 1 m42: 2 m48: 2,2 m54: 3 m60: 3,2 m66: 3,6	The interoperability improved from 1/5 to 3,6/5.
I2) Accessibility of open data	Apr 2020 (M31) – Mar 2023 (M66)	Baseline m30 Mar 2020: 3,02 m36: 3,02 m42: 3,18 m48: 3,18 m54: 3,17 m60: 3,12 m66: 3,97	The average rating of the open datasets on the Berners-Lee 5-star scale improved from 3,02 to 3,97.
I3) Increase in online government services	Apr 2020 (M31) – Mar 2023 (M66)	m36: 1 m42: 1 m48: 2,1 m54: 2,9 m60: 3,1 m66: 3,9	The access to online services constantly improved during the monitoring period and was good (3,9/5) at the end of the monitoring period.

I5) Quality of services through open APIs provided	Apr 2020 (M31) – Mar 2023 (M66)	m36: 1 m42: 3 m48: 3,5 m54: 3,5 m60: 3,6 m66: 4	The quality of services through open APIs constantly improved during the monitoring period and was good (4/5) at the end of the monitoring period.
I4) New open data sets by type of services	Apr 2020 (M31) – Mar 2023 (M66)	Baseline m30 Mar 2020: 117 m36: 117 m42: 146 m48: 146 m54: 154 m60: 222 m66: 277	The number of open data sets increased from 117 to 277.
I7) Number of new ISO 37120 KPIs calculated	Apr 2020 (M31) – Mar 2023 (M66)	Baseline m30 Mar 2020: 0 m36: 0 m42: 0 m48: 23 m54: 23 m60: 23 m66: 23	23 new ISO 37120 KPIs calculated

Appendix E – Tables SPARCS

E1. Impacts on provisioning systems. SPARCS.

Advanced modeling & simulation
Virtual twin of Sello
Simulation and optimization of energy performance in real buildings. Help city planners test infrastructure scenarios in real urban contexts
Control system & energy management
Leipzig Zero, a smart socket prototype
Support smart home integration, user engagement, flexibility potential
ICT for positive energy blocks (Sello Shopping Center)
Integration of EV chargers, PV, HVAC and building automation, lead to increased flexibility in energy demand, cleaner energy system
ICT integration
(blank)
VPP solution for public buildings
enabled demand response functions using EV charging infrastructure
Data platforms
Human centric application
Energy efficiency systems
Integration of RES
Improved transparency of energy generation and consumption across the local grid
Visual metaphors and dashboards for footprint analysis
-
IoT & smart infrastructure
Integration of open standardized sensors and systems.
Enables smart waste, parking, and environmental monitoring across Leipzig districts
Smart heating
Improved flexibility in heating systems of social housing

E2. Social impacts. SPARCS.

Advanced modeling & simulation
Virtual twin of Sello
support strategic planning and city level simulations
Control system & energy management
Leipzig Zero, a smart socket prototype.
user awareness, engagement and participation in energy use
ICT for positive energy blocks (Sello Shopping Center)
(blank)
ICT integration
(blank)
VPP solution for public buildings

(blank)
Data platforms
Human-centric application
Facilitate self-monitoring for end-users in residential communities, raise awareness on energy consumption
Integration of RES
(blank)
Visual metaphors and dashboards for footprint analysis
aim to let consumers compare their performance with top-performing consumers to change bad energy behavioral patterns
IoT & smart infrastructure
Integration of open standardized sensors and systems.
indirect impact via improved urban services and infrastructure
Smart heating
not reported

E.3 Technical impact SPARCS

Advanced modeling & simulation
Virtual twin of Sello
Uses 5 technologies for energy forecasting
Control system & energy management
Leipzig Zero, a smart socket prototype.
400 smart sockets deployed.
ICT for positive energy blocks (Sello Shopping center)
Integration of smart flexibility platform, predictive energy models and partial VPP integration
ICT integration
(blank)
VPP solution for public buildings
Implemented Siemens-based control logic for real-time power adjustments in EV charging infrastructure as flexible loads.
Data platforms
Human-centric application
smart meters installed in 27 apartments; application enable time-specific consumption analysis.
Integration of RES
Deployment of digital platforms to monitor and manage energy data from PV, heat pumps
Visual metaphors and dashboards for footprint analysis
real-time feedback via analytics and comparison
IoT & smart infrastructure
Integration of open standardized sensors and systems.
use of LoRaWAN technology for low-power, long-range communication with minimal infrastructure
Smart heating

Integration of smart control of heating systems, peak load management

E4. Environmental impacts. SPARCS

Advanced modeling & simulation
Virtual twin of Sello
improved forecasting accuracy, energy savings
Control system & energy management
Leipzig Zero, a smart socket prototype
Aims to reduce peak demand but impact not measurable due to low usage
ICT for positive energy blocks (Sello Shopping center)
CO_2 reduction through energy optimization (27 tones CO_2 equivalent reduction, p. 32)
ICT integration
Expected to reduce emissions through peak shaving and low-carbon district heating integration
VPP solution for public buildings
no direct emissions data but potential for grid load balancing and energy efficiency.
Data Platforms
Human-centric application
reduce total and peak electricity via behavioral shifts, however direct savings are not yet available.
Integration of RES
Increased use of renewable energy, reduction in CO_2 emissions
Visual metaphors and dashboards for footprint analysis
aimed at reducing CO2 emissions and energy use
IoT & Smart Infrastructure
Integration of open standardized sensors and systems.
indirect by enabling technologies for resource-efficient urban management.
Smart heating
13.82 tons of CO_2 savings in the 8 buildings over the monitoring period

Appendix F - Tables cross projects

F1. External trends, per project and ICT category:

GrowSmarter
Advanced Modeling & Simulation
Increasing demand for sustainable urban planning.
Control System & Energy Management
Data privacy concerns, smart living trends, sustainable development, energy transition
Demand for reducing operational costs, EU energy-efficient polices
Energy consumption
EU energy efficiency policies, increased demand for digital solutions, consumers interest in energy savings (OBS own observations)
Peak shaving will be a major topic due to the forecasted congestion of electrical grids in cities
Regulations, renewable energy.
Renewable energy act
(blank)
Data Platforms
digital mobility tools, sustainability in urban transport, apps
EU regulations and open data policies. Digitalization.
EU regulations and open data policies. Digitalization. Climate change. Urbanization.
GDPR, software development, legal considerations, climate policy (clean energy package)
(blank)
IoT & Smart Infrastructure
EU smart city initiatives have increased focus on real-time traffic and environmental monitoring.
Falling costs for technology
Growing demand for connectivity
Legal and regulatory constraints on waste collection and data management
Legal frameworks
Safety for citizens, developing technology. Lowering emissions.
Sustainable mobility reduced urban emissions, app-based systems.
MAtchUP
Advanced Modeling & Simulation
(blank)
Control System & Energy Management
EU frameworks/policies, data visualization tools, higher costs.
(blank)
Data Platforms
Expectations for transparency, open governance
governance, need to improve decision making
Pressure for integrated decision support
Push for interoperable digital infrastructure across EU cities
(blank)

IoT & Smart Infrastructure
(blank)
RUGGEDISED
Advanced Modeling & Simulation
Digitalization, climate change, open governance demands
Control System & Energy Management
climate neutrality targets. Public-private data governance. Digitalization. Digital governance.
climate targets, Paris Agreement (Umea)
EU/local pressure to reduce energy demand and integrate renewables in public infrastructure.
Glasgow aims to meet net-zero carbon by 2030. Need for commercial sector decarbonization.
Net Zero 2030, energy price volatility.
Data Platforms
citizen participation, digital governance
Digitalization, open data governance, climate policies (sustainable Glasgow plan & green new deal). Interoperable urban data systems.
sustainability education, awareness in digital tools in schools/public buildings.
(blank)
IoT & Smart Infrastructure
City's CO_2 reduction goal. 65% sustainable travel by 2022. Sustainable mobility.
SPARCS
Advanced Modeling & Simulation
smart urban planning, climate change
Control System & Energy Management
Demand for energy monitoring
energy transition goals, need for decentralized grid flexibility
Need for consumer engagement in energy transition.
(blank)
Data Platforms
energy awareness, digital tools, application
EU renewable energy targets
rising energy prices, climate policy, digitalization.
IoT & Smart Infrastructure
Digital transformation, urban infrastructure
ICT, energy systems

Table F2. Challenges per category.

Advanced Modeling & Simulation
Coordination challenges between municipal departments. Ensuring data availability.
forecasting impacted by data collection transitions and external data quality, e.g. PV forecasts (p. 41)

No numerical results – difficult to measure impact. Data ownership, standardization, vendor lock-in, governance issues.
(blank)
Control System & Energy Management
.
10 e-buses were bought but due to the timeline of the project they have not been monitored.
battery fire safety, delays, electrical issues in battery location
Connecting and controlling power systems to a new external control. Time-consuming to collect software and equipment requirements, retrofitting delays can affect implementation. Impossible of monitor electricity consumption at individual dwelling level.
Covid 19 delays, configuration issues
Data confidentiality restrictions, which limited the ability to fully analyze individual household consumption.
Due to permission hold-ups and the price volatility in the energy asset market (due to the war in Ukraine) there was no implementation of the solar thermal plant, therefore not monitored and cannot be assessed. The plant construction started in March 2024 but is outside the SPARCS timeline.
Finding suitable public buildings, low financial viability of building-based loads
Interoperability issues. Highly competitive market. Low value and digital engagement among residents.
Lack of awareness. Mistrust of the importance of energy consumption monitoring. End-user challenges regarding the tenants' lack of tech knowledge
Large datasets, technical challenges regarding the integration of the system (depending on the battery inverter manufacturer).
Network security challenges, challenges with coordination between multiple building owners and data access limitations.
Required tenant education and engagement for effective use, installation complexity. Improving battery life presents a challenge: the longer they last the more convenient.
Requires coordination with city departments and adapting planning needs
system calibration complexity, integration into older buildings
Technical barriers in integrating legacy systems.
Technical issues with wifi connectivity and socket software paused rollout. The low usage affected data quality. Only 400 out of 1000 were deployed.
The weather variation affected the predictability, differences in building thermal mass.
Trust and privacy concerns, hesitancy towards uncertified meters. Citizens not familiar with the technology. Sensitive economic feasibility.
Unclear data-sharing agreements between public and private partners.
(blank)
Data Platforms
4 ICT actions monitored as one
Challenging target groups (older people may not have smartphones). Technical challenges related to the GPS function, which consumed a lot of battery power from the phones. Unclear long-term user adoption, underestimated development costs.
Concerns about data provision. Legal barriers to data sharing.
Data standardization, stakeholder engagement (convince stakeholder to publish data).

GDPR compliance, data quality responsibility, timing of data gathering added costs and complexity.
Having enough data to fill the platform with.
High development costs. IoT security risks. Complexity in integrating data from various devices. Dependence on existing IoT devices. Skills to leverage the data for new business development. Reluctance of citizens towards monitoring and control (handbook p. 13)
Main challenges are around sensor technology and the data quality from the sensors. Time-consuming to implement new sensors. Uncertainly how to differentiate bicyclists from pedestrians.
technical integration with legacy systems, ensuring usability for non-technical users.
User engagement and relevance over time.
(blank)
IoT & Smart Infrastructure
Tenants' participation due to privacy, certification concerns, engagement difficulty.
4 ICT actions monitored as one
Design complexity, pandemic impacted follow-up of the solution.
GDPR restrictions on waste data, tenant consent issues, higher than expected energy consumption
High costs of network access, system use, and issues related to data costs were long-term challenging. Lack of regulations forcing taxis to use stands. Consumers prefer to be picked up at their specific location rather than at taxi stands. Challenging to monitor and evaluate results.
Large number of sensors were needed to see more impact on a larger scale.
Limited technical effect during test period
Not economically sustainable in Sweden due to low electricity prices, long pay-back time. Maintenance of these smart lights could be challenging with evolving technologies.
Technical limitations of Wi-Fi based sensors, high initial costs, lack of standardized sensor protocols. Few users and little added value.

Table F3. Enabling factors per category.

Advanced Modeling & Simulation
Growing demand for data-driven urban planning tools.
Information. Co-creation with private sector. Integration with other solutions (R8)
Support from VTT, research institution. Use of APIs allowed integration with Virtual Power Plant and other applications.
(blank)
Control System & Energy Management
Being embedded in VLCi urban platform architecture
cooperation from property owners and smart infrastructure baseline.
Developed in coordination with municipal infrastructure. Market focused on IoT. Higher energy costs makes people interested in monitoring their energy consumption.
Existing district heating infrastructure, prior business models
Existing infrastructure, multiparter collaboration. Open ICT platform.
Favorable regulations from the government (such as RD244 in Spain), for instance exemptions applied by municipalities. Public incentives for battery adoption

From factsheet: Developing the business model from B2C (Business-to-Consumer) to B2B (Business to-Business) could be a good opportunity to upscale the solution.
Funding by the municipality, part of campaign "Take Charge of Your Energy"
Have a questionnaire follow-up, asking for feedback from the tenants. Good communication.
Have a reliable forecast model for the own flexibility. Collaboration with private sector actors such as Siemens. EU financing. Use of AI.
Integrated with building energy retrofits, gained interest from major building operations.
Need to lower peak loads. Measure the solutions in different kind of buildings.
Partnership with Wheatley Group, smart grid integration
Pre-installed emic devices, existing BMS infrastructure
real-time control system using Siemens logic created effective communication between energy meters and EV charging stations.
Use gamification. Integrate in new construction projects.
(blank)
Data Platforms
Accessible interfaces and integration with building data systems.
Already existing city-scale data platforms, commitment from governance.
Cloud based, modular.
EU funding support, Standardized APIs, public private partnership
Financed by municipal funds. p. 159
Increasing interest among citizens in smart solutions. Growing demand for data usage in specific applications (handbook, p. 13)
Stakeholder engagement, clear visual identity.
Strong municipal open data policy and technical support for CKAN p.23
Strong municipal ICT strategy, open data polices
The city platform supports documentation and testing endpoints.
University engagement, municipal policies, clear data descriptions.
User-friendly design of app
(blank)
IoT & Smart Infrastructure
Awareness campaigns for the residents' participation, potential system upgrades for energy efficiency
Cloud-based data hubs.
Cooperation between multiple landowners
Leveraging existing SmartHome users.
Partnership with Espoon Asunnot Oy (housing company) enabled scaling.
Standardization could help speed up permitting or reduce prices. Feeling of safety is important.
Standardization of camera-based sensors improved feasibility, data were useful for multiple stakeholders. Ask the end-users for their needs instead of just putting up sensors in an area and hoping for application potential. Economic feasibility in the long term.
Use existing lightning infrastructure

Table F4. Impacts on provisioning systems per ICT category.

Advanced modeling & simulation
Improved integration of energy, mobility, waste and lightning systems. Enhances planning efficiency.
Simulation and optimization of energy performance in real buildings. Help city planners test infrastructure scenarios, in real urban contexts.
Supports planning.
Control system & energy management
18-27% of electricity savings per household (measure combined with retrofitting).
Allowed tenants to monitor and control electricity heating and water via an app.
Enabled demand response functions using EV charging infrastructure.
Enabled real-time monitoring and optimization of energy in residential and office buildings.
Enables energy demand response and visual analytics.
Enables integrated control of heating, solar, grid and storage systems.
Enhances residential energy efficiency, reduce overall energy demand, link with city-level data.
Improved efficiency of heating, cooling and ventilation through digital control.
Improved energy efficiency in buildings.
Improved grid efficiency through peak shaving.
Increased grid flexibility, enabled smart control of commercial energy loads.
Installed in individual homes and does not impact broader urban systems.
Integration of EV chargers, PV, HVAC and building automation, lead to increased flexibility in energy demand, cleaner energy system.
Provided real-time electricity consumption insights for users, helping the city collect residential energy profiles.
Reduced demand on district heating networks. District heating providers can avoid the use of peak loads unit and therefore save money and reduce negative climate impact at city-level.
Supported smart home integration, user engagement, flexibility potential.
Supported uptake of renewable energies and grid flexibility. Allow citizens to feel benefit of a micro-grid system.
Supported a partly self-sufficient energy supply, reduces grid pressure, integrate EV charging to local systems.
Data Platforms
Better mobility management.
Complementing L12.
Data will impact strategic decisions of the cities mobility improvement areas.
Improved energy efficiency systems.
Improved energy efficiency in public buildings.
Enhanced planning. Support energy, mobility and urban services.
Facilitated the integration of new services into VLCi platform. Interoperability.
Improved city planning, support smart energy, mobility and environmental management.
Improved transparency of energy generation and consumption across the local grid
Increased in online government services from 1/5 to 4.5/5. Improved interoperability from 1/5 to 3.7/5.

Promoted sustainable ways of transport.
Reduced traffic jams/improve commuter experience through early alerts.
Supported city monitoring and long-term planning by consolidate data from multiple urban domains. The datasets are connected to smart meters in residential and public buildings, energy generation, e-mobility and charging stations.
Supported city planning and performance tracking.
Supported decentralized energy trading models.
Supported decision-making applications and grant interoperability a standardized management.
Supported third-part innovation and city service integration
Supported intermodal and multimodal mobility coordination
Supported open governance and other smart city services through public data.
Supported sustainable urban mobility.
Used findings to implement other traffic limiting actions. Track vehicle flows. Better decision-making.
IoT & Smart Infrastructure
Enabled smart waste, parking, and environmental monitoring across Leipzig districts
Improved flexibility in heating systems of social housing.
Improved waste management.
Integrated multiple sensors into urban infrastructure to collect traffic and pedestrian data, improve traffic management
More connectivity in the urban area. Provides real time info about the city.
Reduced intervention time in case of emergency. Fewer blackouts, fewer managements costs
Reduction in traffic congestion, potential integration with MaaS platforms.
Several lightning technologies tested, reduced energy.
Supported shift from car use to public transport.
Tenants can optimize their energy consumption which lead to energy savings.

Appendix G – Tables sources

Table G1. Sources per solution per project.

GrowSmarter
HEMS (Home Energy Management System)
Factsheet 11
Active House – Private home energy management system
Factsheet 12
Adaptive LED lightning
Factsheet 19
EcoStruxure Advisor – Energy performance evaluation platform for buildings
Factsheet 15
Energy management system at neighborhood level
Factsheet 17
Energy saving center, an IOT platform.
Factsheet 14
EnergyHUB – smart management of photovoltaics and energy storage
Factsheet 16
Integration of sensor and heterogeneous data in standard data format
Factsheet 30
Monitoring of substations and data collection in central platform
Factsheet 23
Open data platform
Factsheet 27
Open data platform (MetroLIVE App)
Factsheet 28. AND D5.1
Smart connected street environments
Factsheet 22
Smart home system – private home energy management system
Factsheet 13
Smart management of photovoltaics and energy storage
Factsheet 18
Smart meter information analysis and actuators
Factsheet 23
Smart taxi stand system
Factsheet 44
SmartTower solution
Factsheet 20
Travel demand management app
Factsheet 35
Urban models and semi-automatic instance mapping
Factsheet 29

Virtual Energy Advisor –- open city home energy management system
Factsheet 10
Waste collection system
Factsheet 26
MAtchUP
150 smart controls at building level
MatchUp Website
400 smart meters for building
MatchUp Website
Battery storage platform
MatchUp Website
Big Data functionalities
D3.14, p.164.
D5.5, p 99.
Citizen's feedback mobility application
D3.14, p.170.
Demand management and operation of charging systems for the e-bus fleet
D2.23
Demonstration of optimization actions of public lighting
D3.14, p.83
Eco-driving patterns to optimize the performance of electric buses
MatchUp Website
IOT adaptors
MatchUp Website
IoT adaptors
D5.5, p 99.
IOT and Big Data analysis
D2.23, p.26.
IOT data integration with the VLCi smart city platform
Final Handbook, p.13 and D2.23
IoT urban data platform
MatchUp Website
Management of charging systems
MatchUp Website
Management of E-fleet
MatchUp Website
Management of EV parking places
MatchUp Website
Mobility planning application
D3.14, p.172.
New open API developments
D3.14, p.162.

D5.5, p 99.
New open-data gateway
D3.14, p.160.
D5.5, p 99.
Open APIs
D2.23
Open data management
D2.23
Public charging system management
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