D4.4 Interoperability of holistic energy systems in Leipzig

31/03/2023

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Deliverable administration					
No. & name	**D4.4 Interoperability of holistic energy systems in Leipzig**				
Status	Released	**Due**	M42	**Date**	2023-03-31
Author(s)	LPZ, LSW, ULEI, CEN, SEE, WSL, FHG, SUITE				
Description of the related task and the deliverable. Extract from DoA	**T4.2-T4.7 D4.4 Interoperability of holistic energy systems in Leipzig (LSW) M1 – 42** The report provides an overview of the strategies for interoperability in the city of Leipzig. It answers the question of what potentials exist in the city of Leipzig that aim to interconnect systems and organisations based on modern innovations and technologies. The global need to eliminate greenhouse gas emissions make changes in the energy system necessary. This combines with an urban transformation caused by increasing digitalisation. To match the fluctuating energy supply with potentially flexible demand, one strategy is to create ecosystems that enable data exchange of various stakeholders. These are often called “Virtual Power Plants” (VPP) or “virtual energy communities” (VEC). A VPP is a central platform. Here, data are collected, processed and made available for forecasts, etc. The goal of such an ecosystem is to connect relevant stakeholders, such as municipalities, energy operators and service providers as well as end users. Ideally, as much data as possible and necessary will be provided digitally as well as automatically with the help of digital infrastructure in the energy positive blocks/districts. Thus, the energy demand can be optimised through holistic energy control over the whole energy management system. As a further development step, this will enable the development of digital business models for energy aggregation, the implementation of virtual power plants (VPP) and demand side management (incentivisation or automated steering). The platform integration aims at an open, interoperable and scalable architecture capable of integrating renewable energy into the existing grid infrastructure through intelligent grid solutions. In addition to digital infrastructure, platforms should be able to provide data storage and operations management, test and evaluation procedures and GIS-based visualisation. In the long term, this will enable cities and user systems to automatically respond to fluctuating conditions in near real-time and identify patterns and/or problems, which will help make informed decisions and stimulate better use of city resources.				
Participants	LPZ, LSW, CEN, SEE, ULEI, WSL, FHG IMW, SUITE5, FHG IAO				

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Comments			
V	Date	Authors	Description
0.5	31/10/2022	LSW et al.	Assembly of first working version of deliverable
0.8	18/02/2023		First completed draft of deliverable
0.9	20/03/2023	WP leader	Deliverable checked by WP leader and released to the Coordinator and the Quality Manager for quality checking and subsequent submission to the EC.
1.0	31/03/2023	LSW	Coordinator submits the deliverable to the EC.

Dissemination level		
PU	Public	X
CO	Confidential, only for members of the consortium (including the Commission Services)	

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About SPARCS

Sustainable energy Positive & zero cARbon CommunitieS demonstrates and validates technically and socio-economically viable and replicable, innovative solutions for rolling out smart, integrated positive energy systems for the transition to a citizen-centred zero-carbon & resource-efficient economy. SPARCS facilitates the participation of buildings in the energy market enabling new services and a virtual power plant concept, creating VirtualPositiveEnergy communities as an energy-democratic playground (positive energy districts can exchange energy with energy entities located outside the district). Seven cities will demonstrate 100+ actions turning buildings, blocks, and districts into energy prosumers. The impact span economic growth, improved quality of life, and environmental benefits towards the EC policy framework for climate and energy, the SET plan and the UN Sustainable Development goals. SPARCS co-creation brings together citizens, companies, research organizations, city planning and decision-making entities, transforming cities into carbon-free inclusive communities. Lighthouse cities Espoo (FI) and Leipzig (DE) implement large demonstration projects. Fellow cities Reykjavik (IS), Maia (PT), Lviv (UA), Kifissia (EL) and Kladno (CZ) prepare replication with hands-on feasibility studies. SPARCS identifies bankable actions to accelerate market uptake and pioneers innovative, exploitable governance and business models boosting the transformation processes, joint procurement procedures and citizen-engaging mechanisms in an overarching city planning instrument toward the bold City Vision 2050. SPARCS engages 30 partners from 8 EU Member States (FI, DE, PT, CY, EL, BE, CZ, IT) and 2 non-EU countries (UA, IS), representing key stakeholders within the value chain of urban challenges and smart, sustainable cities bringing together three distinct but overlapping areas of expertise: (i) City Energy Systems, (ii) ICT and Interoperability, (iii) Business Innovation and Market Knowledge.

Partners

VTT · Stadt Leipzig · Câmara Municipal da Maia · Kladno · Δήμος Κηφισιάς · Espoo · KONE · Siemens · Plugit · Citycon · ril · Adven · Fraunhofer · Bable · WSL · Leipziger Stadtwerke · Cenero · Verd · seecon Ingenieure · Universität Leipzig · spi Sociedade Portuguesa de Inovação · New Energy World · OR Reykjavik Energy · CTU Czech Technical University in Prague · Suite5 · ЛьвівАвтоДор · Motor Oil · GOPA.com · CiviESCo

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EXECUTIVE SUMMARY

The SPARCS project aims to demonstrate and validate technically and socio-economically viable and replicable innovative solutions for the deployment of smart, integrated positive energy systems for the transition to a citizen-centric carbon-free and resource-efficient economy. This will be done by developing systemic solutions and strategic interventions in the SPARCS lighthouse cities of Espoo and Leipzig.

The focus is on the interoperability between the different energy systems. The report is submitted at the end of the implementation phase of the SPARCS project. The deliverable is an analytical cross-cutting report of outcomes from tasks T4.2-T4.7.

The Lighthouse City Leipzig focuses on two physical districts ("Leipzig West" and "Baumwollspinnerei") and on one virtual district. The virtual district consists of the virtual power plant, where a wide variety of assets are connected to create an optimised energy management system with real-time data. The platform (digital ecosystem) creates added value for Leipzig's energy system between various stakeholders like the city of Leipzig, local companies, and citizens. The exchange of energy data with the various partners forms the basis for the development of the Virtual Energy Community.

In addition, different use cases are being tested, such as the implementation of blockchain technologies, load-balancing, e-mobility charging, and by examining district heating more closely with a study, etc. Finally, macro-level demonstration actions by the city of Leipzig are also part of SPARCS, in order to systematically extend the positive energy community. This step will be the main focus during the replication phase.

Finally, recommendations and an outlook are given.

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1. INTRODUCTION (LSW, LPZ)

1.1 Purpose and target group (LSW)

The main focus of the SPARCS project is to enable the urban transformation in cities towards Positive Energy Districts (PEDs). The basis for this development is digitalisation to enhance energy management systems based on ICT platforms. The need for interoperable interfaces grows, to allow for data and information from multiple distributed and heterogenous sources to be mapped, combined, visualised and used as a basis for informed decision making by decision makers.

This report provides an overview of experiences of the SPARCS Leipzig project partners with smart energy solutions for Leipzig to become climate neutral. In a cross-cutting analytical overview, it identifies the challenges and further requirements for the implemented solutions to become as interoperable as possible. It answers the question: How do existing solutions need to be modified, extended and complemented to allow for a fully renewable energy system in the future?

The report is aimed at people active within Leipzig and the Leipzig region interested in fostering the local energy transition, as well as at actors from other cities on the same path. It can also be of interest for other Smart City actors and Smart City projects. It can also be of interest for other lighthouse projects and cities, and stakeholder partners as well as cities starting to plan similar types of Smart City development.

1.1.1 Structure and classification of the report to other deliverables

This report is an analytical extension of the preceding report D4.3. Whereas D4.3 provides an overview of the state of the implemented tasks within SPARCS Leipzig, this report D4.4 is a cross-cutting analysis of outcomes of T4.2-T4.7 with regard to interoperability, and it focuses on challenges and prepares the replication of implemented solutions.

The aim of the report is to describe what is necessary to make the measures taken fully interoperable, that is, fully functional for an energy system full of (fluctuating) renewable energy. This deliverable presents the different energy solutions which have been deployed in SPARCs and it reflects how they contribute to the energy transition in Leipzig, and which kinds of modifications they need to be extended to the complete city.

1.2 Partners' contributions

The following Table *1* depicts the main contributions from partners working on this deliverable.

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Table 1: Partners' contributions

Partner	Contributions
LPZ	Chapter: 1: Introduction, 2: Leipzig city vision in the light of Leipzig's Digital Transformation Agenda and Leipzig's climate targets, 3.4 & 3.5 Planning energy communities
LSW	Chapter 1 "Introduction", 2: Interoperability - Importance for the city of Leipzig, 2.3 Overview SPARCS Demo Districts, 2.4 Energy systems, 3: Holistic energy systems, 4: Core results and outlook
CEN	Chapter: 2.3 - 2.4 Energy systems: Baumwollspinnerei, 3: Holistic energy systems, 3.2 - 3.4
SEE	Chapter: 3.3.1 Community support for energy transformation in the district
WSL	Chapter: 2.3 - 2.4 Energy systems: Leipzig West, 3: Holistic energy systems, 3.2 - 3.4
ULEI	Chapter: 3.2 Leipzigs Positive Energy Communitys
FHG IMW + IAO	Chapter: 3.4 E-mobility integration

1.3 Relations to other activities

Table 2 below depicts the main relationship between these deliverable and other activities or deliverables within the SPARCS project.

Table 2. Relationship to other activities in the project

Deliverables / Milestone	Contributions
D4.1	D4.1 (due in M12), which reports a detailed plan of demonstrated actions and sub-actions in Lighthouse City Leipzig.
D4.2	Mid-term report on the implemented solutions for energy positive blocks in Leipzig (M24)
D4.3	Supports D4.3: Implement solutions for energy positive blocks in Leipzig (due in M36).
D4.5	EV mobility integration and its impacts in Leipzig (due in M42)

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2. LIGHTHOUSE CITY LEIPZIG ON THE WAY TO BECOMING A CLIMATE NEUTRAL AND SMART CITY (LPZ, LSW)

For many years, Leipzig is on the way to improving its climate protection and to the further development of its services by using the best - including smart - solutions. The SPARCS project brings together these ambitions by providing smart solutions for the energy system.

Therefore, this section starts with an introduction of Leipzig's climate targets and its principles for the digital transformation as manifested in official documents and highlights the connection to interoperability.

2.1 Leipzig's vision: Climate targets and the digital agenda (LPZ)

2.1.1 Leipzig's targets and actions for climate neutrality

Leipzig is to become carbon neutral at the latest by 2040 (SECAP 2030 = Sustainable Energy and Climate Action Plans) and, by participating in the EU Mission "100 climate neutral and smart cities in 2030", it committed itself to endeavouring to become climate neutral as early as in 2030. Leipzig is in the middle of a process of aligning a coherent climate protection and adaptation strategy, setting up a monitoring system, installing new and adjusting current procedures to meet climate ambitions. While, recently, a new SECAP (EKSP 2030, city council decision taken in October 2022) was adopted with the aim of becoming climate neutral by 2040 (Greenhouse gas emission budget calculated for reaching 1.5°C with an 83% probability, resulting in a remaining budget of 29,000 million tons CO2eq), the recent participation in the EU mission "100 climate neutral and smart cities by 2030" confirms that an earlier date is envisaged.

Currently, SECAP is the most up-to-date strategic document. It is divided into 7 action fields which contribute to 10 so-called "success factors", and it is specified in more detail in biannual implementation plans. SPARCS is part of action field 5 ("Climate-just district development") and also touches on action field 2 "Municipal energy and heat provision". Building VPPs for providing on-demand energy supply is a measure in the Climate Action Plan 2023-24 (No III.3).

SPARCS in Leipzig consists of two physical demo districts and a virtual demo district that bundles city-wide measures- all with the aim of reaching climate positive districts by increasing territorial renewable energy production, flexibilizing demand, and matching production and demand. Whilst some SPARCS measures result in concrete energy assets and measurable energy production, the SPARCS Leipzig team takes care to align the strategic activities with the city-wide processes, laying the ground for new procedures. This is intended to demonstrate how district greenhouse gas

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emissions can be reduced to ensure Leipzig's contribution to the global climate protection efforts.

In a climate-neutral Leipzig, energy will come from renewable sources. The cheapest and most available sources (wind, PV) provide fluctuating energy; manageable renewables are very limited (biomass, wood, hydrogen converted from electricity). Energy demand, however, must always be met with the same quantity of supply. To secure that, demand and supply (1) must be matched – either directly, by moving shiftable loads to times with available supply – or by using storage (2). All assets available for this must be able to cooperate: to transmit information on what is needed, to react to the conditions, and to transmit energy. In this context interoperability refers to all given standards, protocols, measures, processes and guidelines to ensure that different energy assets in the system are able to interact. Only by ensuring this interoperability allows the provision of flexibly to the fluctuating supply and match it to the respective demand. As this requires the use of large amounts of data, it touches on Leipzig's principles for digitalisation, which will be explained below.

2.1.2 The digital agenda of the city of Leipzig

In February 2023, the city of Leipzig established its digital transformation agenda, called the "Digital Agenda". The Digital Agenda of the city of Leipzig applies to the city administration, its public enterprises, and its municipal holdings. It supports interdisciplinary and integrated collaboration within the municipality, as well as with the city society, business, and science communities. Together with the cross-cutting theme of the Digital City in the integrated city development concept (INSEK), the Digital Agenda is the basis for statements on digitalisation projects and initiatives in departmental and administrative strategies, public enterprise strategies, and municipal holdings strategies.

In its Digital Agenda, the city of Leipzig describes the contributions of digitalisation to the implementation of strategic goals. It defines seven guiding principles that the city

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[1] Theoretically, there are three cost-imperfect extreme options for renewable energy systems:

1) Having gigantic production capacities, so that, even during minimum production times, the full demand can still be met (everything full of wind turbines, huge transmission lines across the entire continent, ...)
2) Having huge storages, so that, in case of doubt, peak demand can be met by stored energy (very expensive)
3) Having extremely flexible demands. Shift the demands to times with sufficient supply to ensure 10hat all the energy is used with a minimum of storage and production capacities.

A cost-optimal and practical solution lies somewhere in the middle.

[2] Storing energy is possible, but it is a "last" option: Storage is expensive, and it always leads to conversion losses. So, in any system, to minimise costs, one will try to keep the need for backup storage as low as possible whilst securing functionality.

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of Leipzig will adhere to in shaping the digital transformation, and six areas of action with goals and current projects that it will implement by 2026. In its Digital Agenda, the city of Leipzig agrees on responsibilities, decision-making processes, and further steps for implementation.

Its seven guiding principles are:

1. Digitalisation should serve the people.
2. The city of Leipzig uses digitalisation to jointly and sustainably develop the city.
3. The city of Leipzig acts autonomously, transparently, and responsibly.
4. The city of Leipzig enables people to participate in digital life.
5. The city of Leipzig collects, connects, and shares data for the benefit of the community.
6. The city of Leipzig promotes digital development pioneers.
7. The city of Leipzig offers its services online, securely, and without barriers.

The city of Leipzig shapes the digital transformation cooperatively in six central fields of action. In these, the city of Leipzig has set goals and specified key digitalisation projects as examples (figure 1).

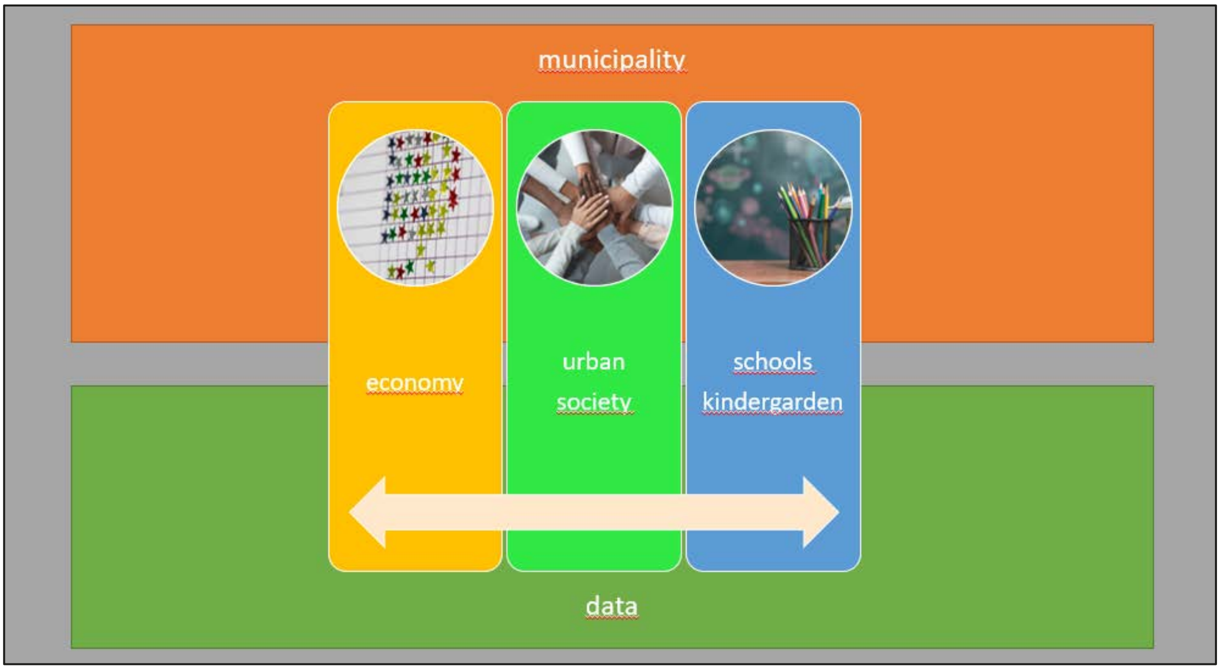

Figure 1: The fields of action of the Leipzig Digital Agenda

The action fields in the digital transformation are as follows:

i) **Data:** Develop and manage the city sustainably with data.
ii) **Economy:** Digitalise services, attract talent and skilled workers, and develop the IT location.
iii) **Networks:** Develop the city safely and efficiently.

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iv) **Urban society:** Shape democracy and strengthen participation.
v) **Leipzig city administration:** Offer digital services and remain personally accessible.
vi) **Schools and day-care centres:** Media education and digital infrastructures.

Relation to the fields of action and guiding principles of the Digital Agenda

Action fields involved

A virtual power plant concerns the action field of networks, data, economy and urban society. A virtual power plant integrates various dispersed energy sources and loads via safe and efficient networks (iii), helping to secure the energy supply. For this, data need to be available and transferable in real time (i). By providing this up-to-date infrastructure in an interoperable manner, the city makes itself attractive to new energy service providers (ii), to offer excellent services. Furthermore, a virtual power plant also helps to integrate plants and projects from the civil society (iv), strengthening urban participation in the field of energy. To make this possible, assets connected to the virtual powerplant need to provide data about their states in an interoperable way, and the virtual power plant needs to be shaped so as to ensure that various assets can be effectively connected.

Applying guiding principles

An interoperable virtual power plant is a pioneer project for digital development in the field of energy (6) and shall be designed to serve the common good of all citizens, local businesses and other stakeholders (1). It needs to be designed to collect, connect, and share data for the benefit of the community (5), enabling people and stakeholders to digitally participate in the energy market (4). The virtual power plant needs to be developed in a cooperative manner (2) and be carried out in a responsible, transparent manner safeguarding Leipzig's autonomy (3). The unique proposal of Leipzig's virtual power plant, based on these guidelines, is the combination of technological factors such widespread IoT devices and state-of-the art machine learning methods on the one hand and community engagement and incentive programs on the other hand.

2.2 Interoperability - Importance for the city of Leipzig (LPZ, LSW)

The term interoperability as used in this report focuses on explaining the importance of structural connectivity of energy assets in the lighthouse city of Leipzig. The spotlight is on the presentation of implemented case studies and the identification of obstacles and problems in practical implementation. In summary, interoperability is understood as the ability of heterogeneous (connectivity) and organisational (interacting

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systems/processes) interoperability. The goal is to show how exemplary use cases can be practically implemented, using independent systems to communicate and exchange data efficiently and to make it available on a usable basis. To this end, this report showcases the implemented measures of the three demo districts.

Interoperability is the ability of different systems, devices, or applications to work together seamlessly and effectively. In the context of smart cities, interoperability refers to the ability of different technology systems, such as transportation, energy, and public safety systems, to communicate and share data with each other. This allows for the efficient and coordinated use of resources, as well as the ability to make data-driven decisions that can improve the overall functioning of the city.

For example, an interoperable transportation system would allow real-time data from traffic cameras and sensors to be shared with traffic management systems, which can then optimise traffic flow and re-route vehicles to avoid congestion. Similarly, an interoperable energy system would allow data from smart meters to be shared with energy management systems, which can then optimise energy usage. Interoperability is important in smart cities as it allows for the integration of different systems to improve the overall performance of the city.

Figure 2 briefly summarises the basic definition of interoperability:

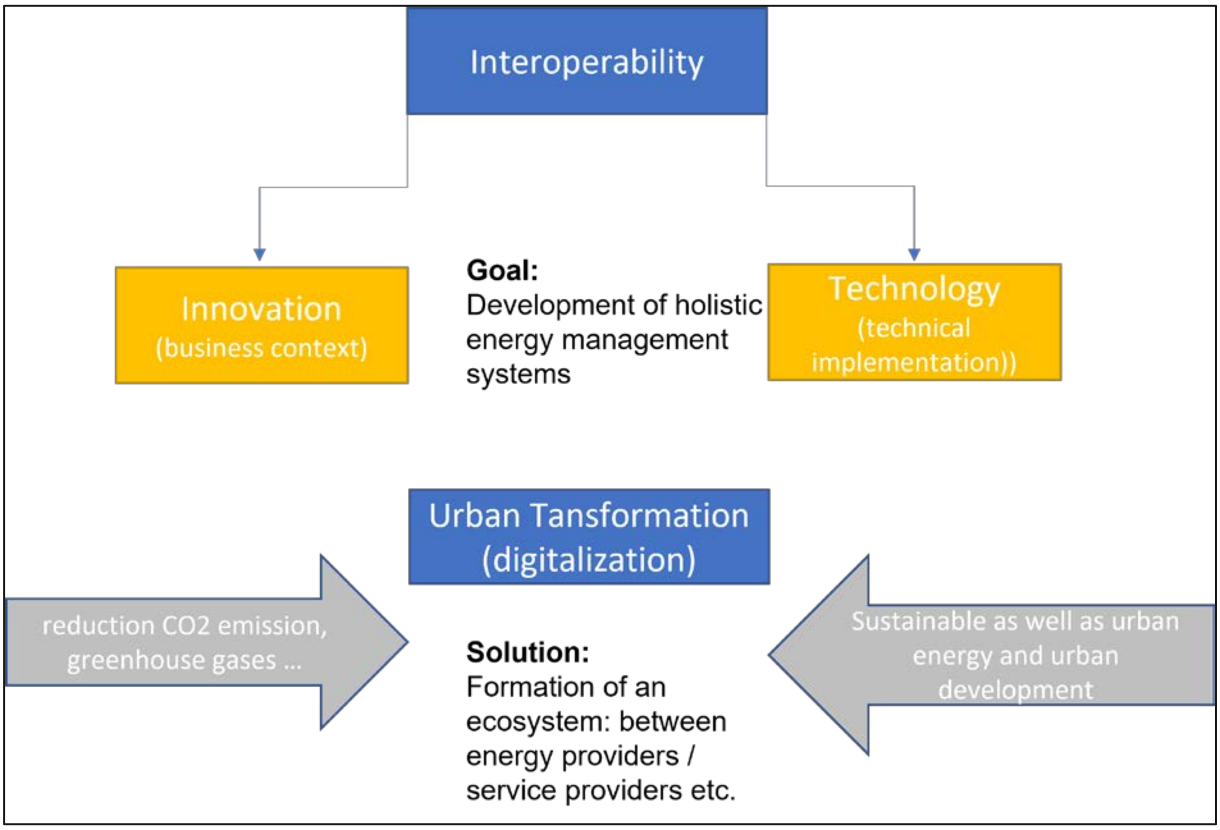

Figure 2: Own representation - A definition of the relationship between interoperability and digitalisation

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Interoperability needs to be implemented technically, and it also needs to fit in the business context of the respective actor. As it can change the current structure of energy management, interoperability is an innovation leading to urban digital transformation.

To allow the integration of distributed renewable energy resources, thereby reducing greenhouse gas emissions, ecosystems of energy providers, service providers and consumers need to be established by developing potent virtual power plants to coordinate effectively between them. The innovative approach is to include other decentralized suppliers and flexible demanders in this power plant. This is an essential goal to ensure the desired interoperability.

Below, we describe the steps taken within the context of SPARCS towards such an ecosystem. For a better understanding of the technical implementation, the virtual power plant (VPP) is presented in more detail in the next section.

How does this apply to interoperability and virtual power plants?

A virtual power plant (VPP) is a software-based platform that connects multiple distributed energy resources (DERs), such as solar panels, wind turbines, energy storage systems, and demand response programs, into a single, coordinated network. This network can then be used to provide various energy services, such as balancing supply and demand, participating in wholesale energy markets, and providing grid stability services (Saboori et al., 2011).

VPPs can provide a means for these utilities to integrate and manage DERs within their distribution system. However, to effectively leverage the benefits of VPPs, interoperability is critical. Interoperability refers to the ability of different devices and systems to communicate and seamlessly exchange information.In the municipal context, interoperability means that the VPP platform can integrate with the utility's existing control systems and data management infrastructure. This enables the VPP to access real-time data about the status of the utility's distribution system, including the current demand for energy, the DER availability, and the grid status (van Summeren et al., 2020).

With this information, the VPP can then optimise the use of DERs to meet the utility's energy needs, minimise costs, and reduce carbon emissions. For example, the VPP can coordinate the use of energy storage systems to shift energy usage from peak hours to off-peak hours, or it can dispatch solar power during times of high demand to reduce the need for fossil fuel-based power generation.

Overall, the interoperability of VPPs with municipal utility systems is essential to enable the full potential of DERs and achieve a more efficient, resilient, and sustainable energy system (Howell et al., 2017).

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2.3 Overview SPARCS demo districts (LSW, CEN, WSL)

In this chapter, three demo districts are presented. These are one virtual and two physical districts in Leipzig. They are as follows:

1. Virtual Energy District:

A virtual energy community (VEC) is a concept where a group of individuals or organisations with a shared interest in energy come together to share resources, information, and collaborate on energy-related projects. It typically refers to a group of households, buildings or businesses that are connected to a common energy management system, allowing them to share and optimise the use of renewable energy sources (Koirala et al., 2016).

VEC can be created using smart grid technology, which allows for the integration of distributed energy resources (DERs) such as solar panels, wind turbines, and energy storage systems. This allows the community to generate, store, and distribute energy among themselves, reducing dependence on traditional utility companies.

A VEC can also be a virtual community that only exists online, where members can share information and collaborate on energy-saving projects without a physical connection. For instance, a virtual energy community could be created to share information on energy efficiency and conservation, or to pool resources for the installation of solar panels or other renewable energy systems.

In the SPARCS context, Virtual Energy Communities are a way to create a more sustainable and resilient energy system, empowering citizens, and communities to play a more active role in the production and consumption of energy. This means bringing

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together energy management systems and connecting different assets via the VPP (figure 3).

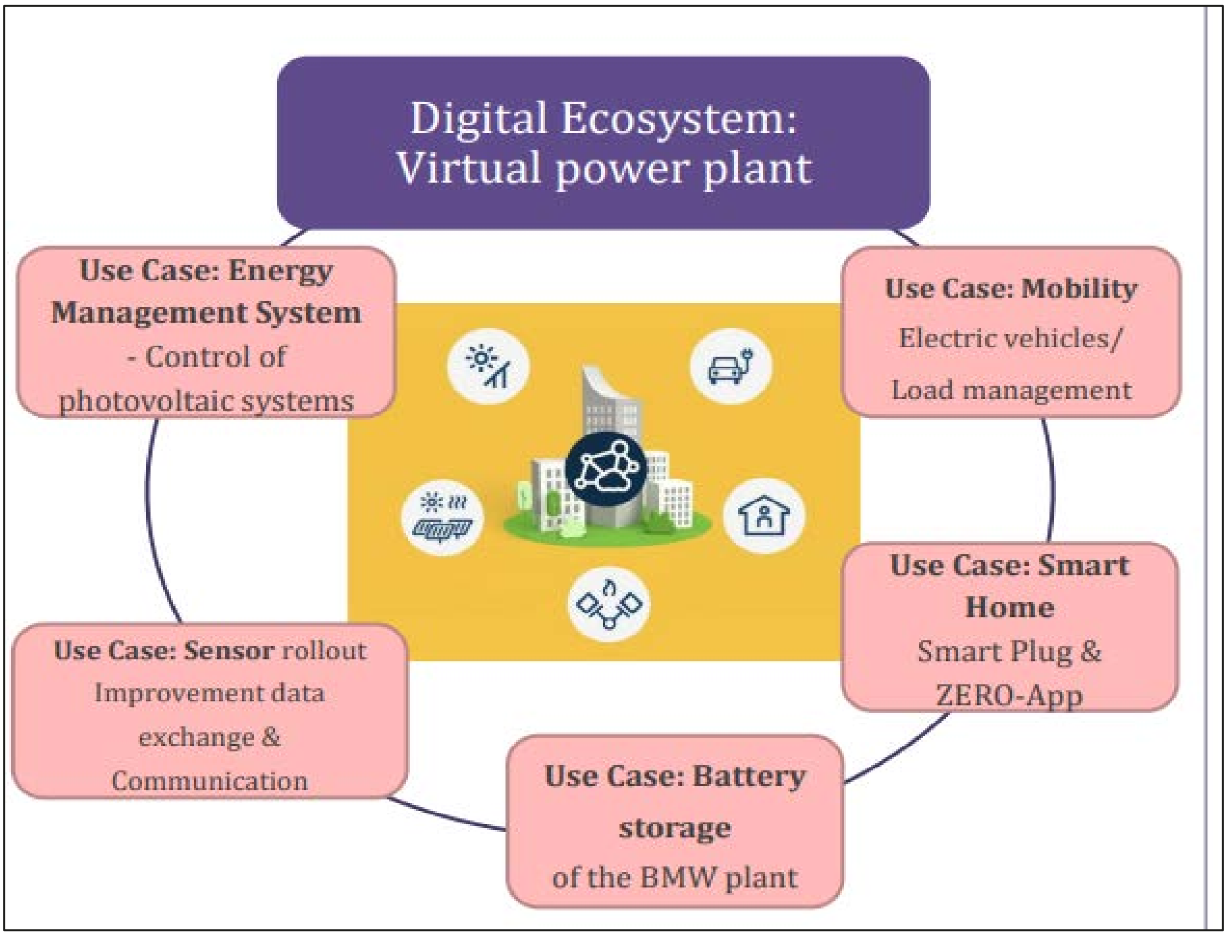

Figure. 3: Own illustration of the Digital Ecosystem SPARCS

2. “Leipzig West”:

The Subtask 4.2.1 “Carbon-free district heating in Leipzig West” is designed to increase the share of RES in the central district heating system. The RES integration focuses on the planning, construction, and integration into the central district heating system of a solar thermal plant, which should supply the residents in the district with low CO_2 heating.

The next step leading to CO_2-neutrality consists in researching what this post-fossil future would look like.

The “Leipzig West” area will be used to create a blueprint for other districts based on each district's specifics (e.g., technologies) (figure 4).

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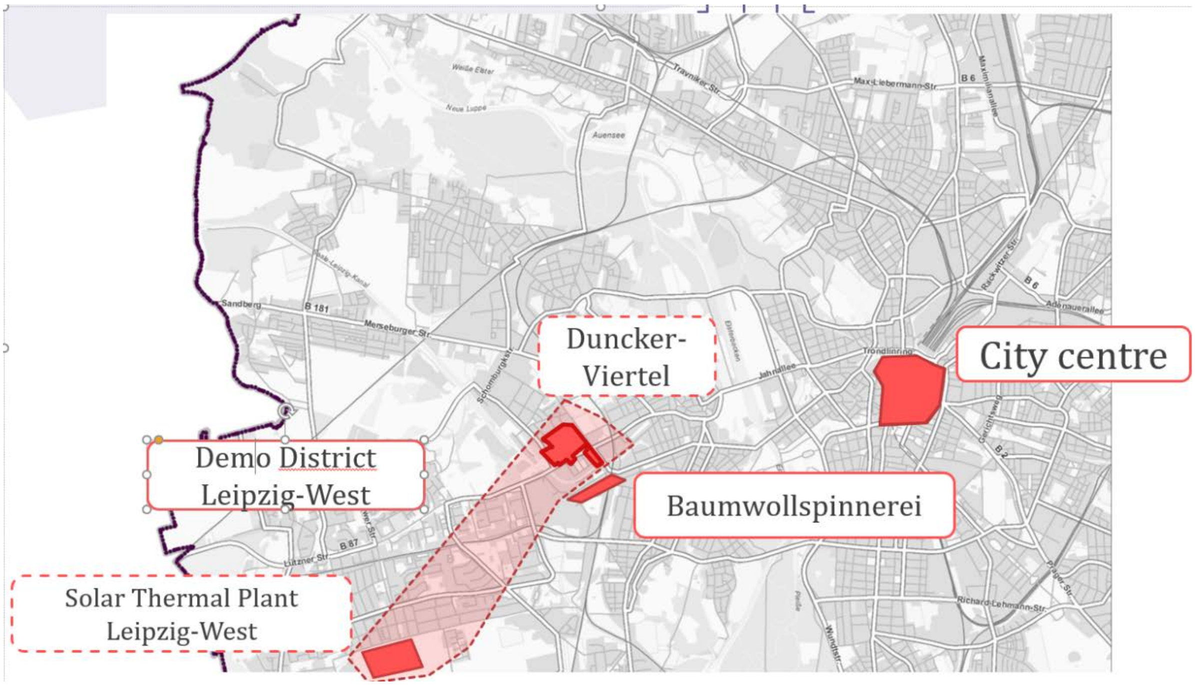

Figure 4: Location of the demo district

3. "Baumwollspinnerei"

The Baumwollspinnerei, a former cotton spinning mill, was built in 1884. This industrial site, comprising numerous buildings, most of which are brick structures, is protected under the Monument Protection Act. The cotton spinning mill was closed in 1993. Since then, the use of the buildings has evolved from single purpose to multi-tenant use. It is now home to artists, commercial enterprises and even residents and is world-renowned, especially amongst the art communities. The buildings with their thick walls and high ceilings comprise an area of approximately 17,000 m^2. The area is a great example of the revitalisation of a former industrial site for cultural activities and includes a StartUpLab ('from cotton to culture'). The buildings used and referred to in this project are halls 14 and 18.

The Baumwollspinnerei will house the microgrid concept developed in the framework of SPARCS. The aim is to generate and store as much decentralised energy as possible in order to increase independence from the upstream public grid. Within such a concept, maintaining a stable grid frequency is of the utmost importance. The microgrid is to be connected to the upstream public grid via a peer-to-peer interface.

As with most older buildings, there are many challenges that need to be overcome on the path to becoming a positive energy district. Often, building plans and power or water distribution plans are inaccurate or outdated. The structural statics of the building can pose a challenge and need to be evaluated in depth. Furthermore, the Monument

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Protection Act restricts many operations and require creative planning to find alternative solutions.

The challenges that arise regarding multi-tenant sites may include the involvement and communication with the tenants. Often, energy optimisation methods require a substantial amount of conscious awareness and physical participation of its consumers, or optionally, automatised demand control strategies that don't need citizend' daily activities, but require more interoperable building energy management systems, smart EV charging etc. Therefore, tenants need to be informed and encouraged to become actively involved. In the case of collecting processing and presenting or visualising data, the relevant privacy laws for the respective countries need to be considered and data security risks evaluated. Sometimes, access to certain areas within the buildings could be a challenge. This should also be considered when choosing the type and location for the implementation of new hardware and software, in order to reduce the challenges going forward.

In addition to the above aspects, one must consider the volatility of a multi-tenant site. Not only may diverse tenants have entirely different energy demands, but tenants may terminate their lease agreement and be replaced with tenants with completely different energy demands.

All these points are aspects that make the Baumwollspinnerei an ideal site for a model for replication in other cities or districts.

2.4 Energy systems - Individual considerations

1. Virtual District

The Virtual District or VPP is the consolidation of assets to implement interoperability on a technical basis. For a uniform understanding in the SPARCS project, the VPP is the Virtual District, together with all the built-up data pipelines, etc. Basically, the VPP is a network of energy-producing, storing, and consuming entities that are virtually connected through advanced control functionalities and dedicated communication channels. The community of entities is spread across various locations, rather than being physically located in one block of densely located buildings. An open standard-based ICT platform, hosted and operated by Stadtwerke Leipzig, has been developed and implemented to achieve optimal control of various energy systems and enhance the district's ability to manage energy autonomously. This platform facilitates the integration of physical energy-related components for generation, distribution, and

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household supply, as well as storage capabilities, such as locally installed storage solutions and mobile storage solutions for temporary capacity extensions. The renewable energy sources include PV, flexible consumers, virtual entities like the BMW battery farm, and other grid participants like charging stations with controllable and actively manageable energy storage systems. This integration allows for remote and active management of devices, depending on environmental or economic determinants.

2. Leipzig West

The Leipzig West demo district includes the so-called “Dunckerviertel” or Duncker neighbourhood. This is an area with 7 existing social housing blocks, comprising, in total, about 300 rental apartments.

The housing blocks are connected to the district heating grid operated by the local energy provider, Stadtwerke Leipzig, with heating transfer stations per housing block, located at the basement of each housing block. These heating transfer stations control thermal energy consumption, regulated according to the outside temperature, of the building and the related apartments. These heating transfer stations form the crucial point for determining the thermal energy consumption, costs and efficiency of the building. There heating cost allocators are installed on each radiator and there are meters for hot and cold water in every apartment to measure the consumption of each apartment and to split up the consumption and costs of the heating transfer station / building once a year. The most common period for settling heating costs is from 01.01. to 31.12. of each year.

At the beginning of the project, the heat cost allocators and water meters had to been read manually once a year. So, the tenants are only informed about their thermal energy consumption for heating and hot water during the last year once a year - in their heating bill.

The idea behind the use of an application is to inform the tenants more frequently and give them an easy and understandable comparison mechanism to help them understand their behaviour and energy consumption and to consistently reduce energy consumption. To implement this, the data collection and evaluation process had to be changed.

In order to collect the data more often than before, new digital meters and heat cost allocators were installed in the apartments. Additionally, a new data infrastructure was installed in the housing blocks. This allows the data connection and data transfer from the housing block to the data server from twice a month to up to daily through data transfer via the internet. For this, internet access points are also installed in the basement of each housing block – also to collect data from the heating transfer station and the control unit.

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In order to positively shape the energy transition, LSW is interested in the expansion of renewable energies. Therefore, the planning of the solar thermal system was included in the application of the SPARCS project. The construction of the plant has been postponed. For the heating network and supply, Stadtwerke Leipzig will build the solar thermal plant to provide thermal energy. The solar thermal plant is the renewable and carbon-free part of the district's heating strategy.

On the other hand, the housing blocks are connected to the public electricity grid. PV plants are installed on some roofs of the housing blocks and can feed the electricity directly into the housing blocks they are connected to or into the public electricity grid.

3. Baumwollspinnerei

With variable renewable energy sources, such as wind and solar, becoming increasingly common and combined with an increasingly intricate consumption structure, such as smart home applications or e-mobility, the management of modern building networks is also becoming ever more complex. At the same time, a highly granular, sophisticated control of volatile energy flows provides great efficiency potential and, thus, the possibility to further reduce emissions.

The development of so-called "microgrids", i.e., smaller and independent grid structures as opposed to supra-regional distribution grids, is based on the approach of decentralised energy production. The microgrid structure is intended to increase the degree of self-sufficiency, by independently supplying energy, as far as possible. In the case of surplus energy, the individual microgrid is to be virtually linked to the public grid. The challenge lies in the technology of the digital links. Combining different producers, consumers and storage facilities within a microgrid is complex and requires sophisticated software to manage and steer the load.

When planning a microgrid, it is important to carefully calculate all consumers within the grid in order to plan the optimal size of the generation plant needed. The frequency of the grid is important, and supply and demand should be balanced as well as possible. It is also not economical to build a too large generation unit. In addition, tenant electricity consumers should always be considered as being variable. The generation units should, therefore, be planned so that they can be scaled up or down as needed (the latter being especially important for microgrids not connected to an upstream grid as grid stability depends on constraints within the microgrid). It is important to collect information not only on the quantities consumed, but also on the chronological patterns of consumption behaviour. This can help to calculate the storage size needed at peak times or at times when variable energy sources are not available (e.g. at night in the case of PV). This investigation should be carried out as thoroughly as possible to ensure optimal grid function and to avoid disruptions or stresses on the grid.

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In order to link the individual producers and consumers with each other and with the interface to the public grid, suitable sensors are installed on site. LoRaWAN radio signalling, with its long range and low power consumption of transmitters, is used for the digital communication. The sensor technology is combined with the central software platform 'cenero.one' (homepage: https://cenero.one/de/de/) energy management system and a load management concept. Using a combination of software and hardware solutions, specifically developed together with Stadtwerke Leipzig, the site (as a microgrid) is coupled to the upstream public grid.

At the Baumwollspinnerei, the generator is a PV plant in combination with storage units in the form of batteries as well as EVs capable of bidirectional charging. The power produced by the PV plant is directly used on site. Excess power is stored in the batteries which can then provide green energy during times when the variable renewable energy source (solar) is not available. Once the storage facilities are fully charged and the supply is still higher than the demand, power is fed into the public grid.

The EVs capable of bidirectional charging serve three functions: They have the potential to provide a means for sustainable transportation provided they are recharged using renewable electricity. They serve as an additional storage capacity, which enhances the efficiency of the PV plant. Furthermore, together with an energy management system, it improves grid stability. A grid is put under strain not only when the energy flow is too low, but also when the flow is too high. The bidirectional charging concept assists in balancing the load in the grid. During times when power generation is high and consumption is low, the battery in the vehicle charges, removing load from the grid and storing it. If, in turn, power generation cannot sustain the demand, power can be taken from the vehicle's battery and reintroduced into the grid in order to maintain the stability of the grid.

Moreover, within the microgrid at the Baumwollspinnerei, intelligent thermostats are installed on the heaters in the rental spaces and linked to an energy management software, cenero.one. The desired temperature levels as well as heating schedules can be entered. Once there is no more demand for heating individual rental areas, a control command is sent to the heat distributor in the technical rooms via the LoRaWAN radio protocol and the affected distribution line is switched off until heat is needed again. The thermostats have intelligent learning capabilities and can, therefore, provide a prognosis of the heat demand in advance. This function has the potential for extensive heat and electricity savings and waste reduction.

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3. HOLISTIC ENERGY SYSTEMS (LSW, WSL, ULEI, CEN)

3.1 T4.3 ICT and Interoperability in Leipzig Lighthouse Demonstrations (LSW)

3.1.1 Digital transformation of the energy industry

The term "digital transformation" within the energy industry refers to the use of digital technologies such as Internet of things (IoT), big data, and advanced analytics to improve the efficiency and effectiveness of energy production, distribution, and consumption.
One of the main areas of digital transformation in the energy industry is the integration of renewable energy sources, such as solar and wind power, into the grid. This requires the use of smart grid technologies and advanced analytics to manage the variability of these sources and ensure a stable and reliable power supply (Farhangi et al., 2009). In this report, the virtual power plant (VPP) is presented as a practical implementation measure (platform) for building interoperability in the city of Leipzig and described in more detail with the opportunities and challenges.

Another key area of digital transformation is the use of IoT and advanced analytics to improve the efficiency of energy production and distribution. For example, sensor networks and advanced analytics can be used to optimise the performance of power plants and transmission lines, reducing downtime and increasing efficiency.
Additionally, the digital transformation of the energy industry also includes the use of digital technologies to enable new business models, such as virtual power plants, peer-to-peer energy trading and demand-side management.

The emergence of renewable, distributed energy resources (DERs) and smart grids is expected to create a network, in which billions of devices could automatically communicate with each other. The increasing share of these energy resources might establish a zero marginal cost market in which single units of generated power will have no significant costs anymore. Concurrently, competition has an impact on wholesale prices and margin rates. Utilities are pressured to adjust to the change. The energy market is facing changes brought about by technological and socioeconomic developments. The following trends can be observed (Edelmann, 2014; Strüker et al., 2019):

- The energy generation transitions from conventional thermal power plants to DERs, often renewables. This leads to fluctuating supply, increasing uncertainty, and a demand for information services;

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- Energy trade becomes more complex. Local markets are being established, opportunities emerge, and streamlining the digital infrastructure gains in relevance;
- The energy distribution, now utilising bidirectional flows of energy and data, is getting more dynamic (weather-reliant plants, storage);
- The metering infrastructure is becoming increasingly digitised. Modern metering infrastructure and intelligent measurement systems replace analogous meters;
- Customer relations are being confronted with a new kind of well-informed customer who is less reliant on the utility and takes social and environmental issues into consideration.

3.1.2 Challenges in the architecture of digital energy platforms

The ICT Platform is building a digital, intelligent ecosystem with various stakeholders and assets to advance the developments towards a Smart City in Leipzig. The technical provision of the ICT platform is carried out by LSW. This concerns, for instance,

- the ecosystem as a flexible platform in transition,
- lessons learned in the implementation,
- connection of households and
- connection of generation plants.

The target image of the Virtual Power Plant, setting up the ICT platform, generally has the following advantages:

- digitalisation of the city of Leipzig: transformation toward smart city development with a focus on the intelligent use of energy as well as the introduction and consolidation of digital services in specific neighbourhoods (demo cases),
- ICT solutions that enable smart services, such as demand-side management tailored to the customer, highly efficient solutions for prosumer integration and high quality of service.
- Application of data technologies to information provided by ubiquitous smart meter technologies for multisectoral energy use in large cities.
  The future ICT strategy aims to ensure that ICT governance is an integral part of guidelines for policies and organisations (corporate governance).

To address these risks for the energy sector, ICT should be carefully managed to achieve the net positive effects. Multiple factors may play a role in its assessments; for

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instance: Cost-benefit analysis of an ICT platform, fair competition issues, cybersecurity issues from the perspective of IT security in citizen-driven processes, reliability and scalability concerns and funding policy issues. ICT itself is an energy-consuming technology.

For the energy sector, the ICT development is linked to connectivity in the context of IoT. New digital business models and approaches to expand the product portfolio pave the way for the municipal utility of the future. The effective use of this is to be rated as one of the greatest challenges in the transition to ICT due to a (current) lack of knowledge and trust in these systems. Sustainable urban development also addresses the citizen side. A smart city applies ICT to enhance its operational efficiency in order to sustainably improve citizens' quality of life. The energy, water, transportation, health, and recycling subsystems, etc. are all interconnected through ICT to deliver sustainable solutions. Figure 5 represents how the information are being displayed and processed.

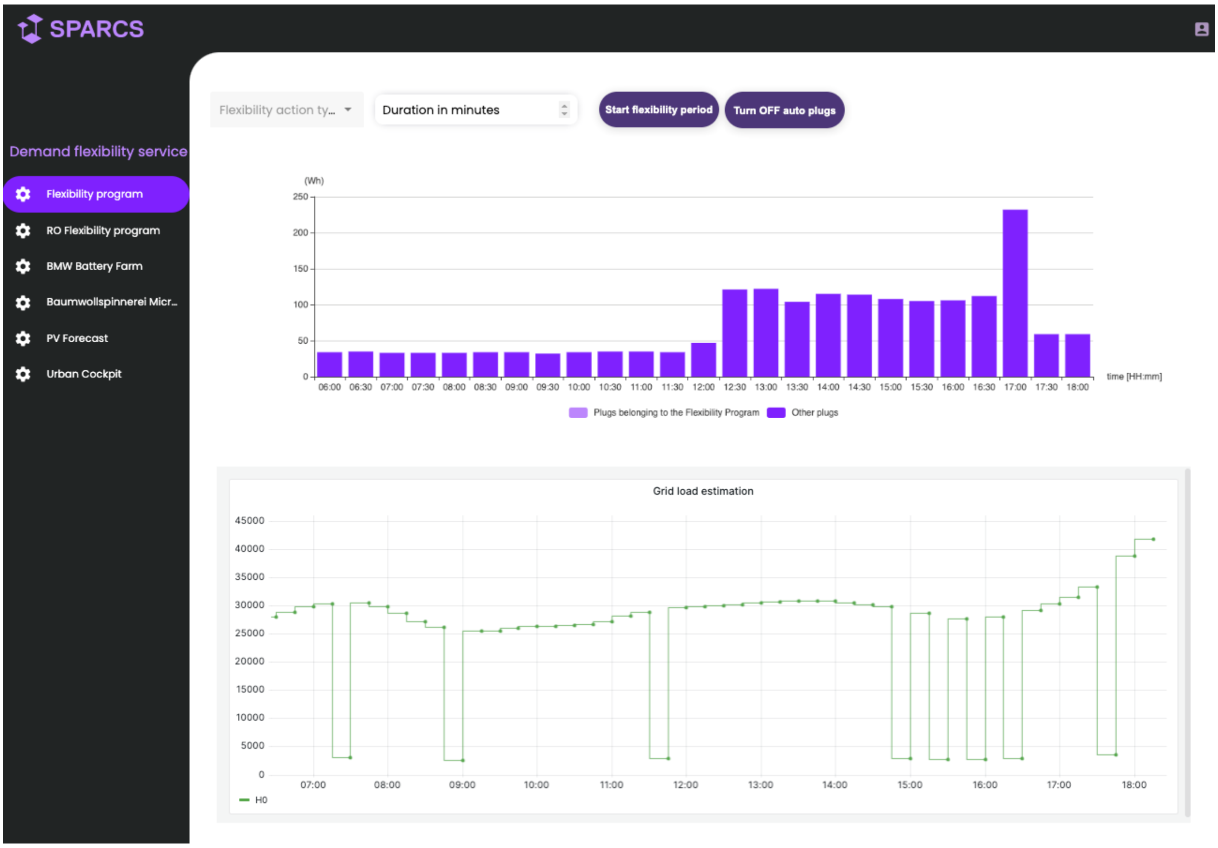

Figure. 5: LSW User View of the Virtual Powerplant Leipzig - Management Dashboard

3.1.3 Determinants of successful interoperable energy systems

In the context of smart city and CO_2-reducing demonstration projects, like SPARCS, the interoperability of information systems forms a critical aspect of developing future

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operational processes for daily life and business in an urban environment. As a result of the increasing need for the seamless integration between different public sector entities, electric utilities, and businesses, there is a growing interest in finding ways to enhance interoperability between various systems. Elements like electricity and heating systems, electric mobility, and other infrastructures require a high level of connectivity and integration to function effectively. Several factors determine the success of interoperability between different systems:

- Standardization plays a crucial role in ensuring that different systems can communicate and interact seamlessly. Standards are essential for establishing uniformity and consistency across different systems, which is crucial for interoperability. They also enable different systems to share data and information using a structured and standardized format, enabling effective communication and integration. Essential for the Leipzig use case was for instance the use of Apache-based software licenses, established IoT standards like MQTT and LoRaWAN, but also open source-based programming languages like python and their respective libararies (e.g. PyTorch for machine learning).
- Data governance is another critical determinant of interoperability between different systems. Effective data governance policies and procedures are essential for ensuring that data is managed and shared appropriately. Data governance frameworks must be established to ensure that data is accurate, consistent, and up-to-date. This is essential for ensuring that different systems can access and use data reliably. In the Leipzig case, the following measures needed to be put in place: We assigned data responsibilities and accountabilities to specific employees (e.g. SPARCS IT project lead) to ensure compliance with data protection requirements. We informed employees about data protection requirements and the consequences of non-compliance. We further established clear agreements inside of LSW and L-Group (e.g. LVB) for sharing data.
- Data integrity refers to the accuracy, completeness, and consistency of data throughout its lifecycle. Data that is inaccurate, incomplete, or inconsistent can lead to errors, incorrect assumptions, and poor decision-making. This can be particularly challenging for systems that rely on real-time data, such as electric mobility or heating systems. Therefore, the establishment of measures to ensure data integrity, such as data validation procedures and data quality checks, is of essential importance. In the Leipzig case, we installed automatic services to check incoming telemetry data for completeness before sending it to the Influx data base.
- Data security and privacy are critical to ensure that data is protected from unauthorised access, manipulation, as well as to protect personal information from misuse. This includes data security measures to prevent cyber-attacks and other security breaches that could lead to system failure, but also internal and

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inter-organisational privacy regulations ensuring that personal data is only shared between different systems when necessary and with the appropriate consent from the data subject. This was also part of the responsibilities of the data governance official (IT project lead), who, on a regular base, assessed which data sets are shared with which stakeholders.

- Data analytics capabilities and, in particular, machine learning play a crucial role in enabling interoperability between smart city elements. Machine learning algorithms can be trained on large datasets to identify patterns, trends, and insights that can be used to optimise the performance of different systems. For instance, machine learning algorithms can be used to forecast future generation, as for instance in the case of the Leipzig virtual power plant, or to optimise energy distribution challenges, as for instance in the case of district heating. Therefore, in the case of Leipzig machine learning capabilities are essential for enabling interoperable, and effective operation of the smart city elements. T4.2 Leipzig's Positive Energy Communities (LSW, ULEI, WSL, CEN)

3.2.1 Introduction of the Virtual Energy Community

Neighbourhood management faces significant challenges when it comes to energy in existing buildings, taking into account technical, regulatory, and legal aspects. One of the most significant technical challenges is that existing buildings were typically constructed without energy efficiency in mind. As a result, they may lack proper insulation, have outdated heating and cooling systems, and may not have energy-efficient lighting or appliances. Retrofitting these buildings to improve energy efficiency can be costly and time-consuming. It is important to gather a comprehensive database of the building with as much information as possible. Question, such as where and how energy is generated, how it is distributed or stored, who is consuming it and for what purpose, should be addressed. Furthermore, quantitative information on the consumption amounts and patterns should be analysed and losses and weaknesses in the systems identified. Technical compatibility of new innovative technologies with older technologies should also be investigated in planning.

The timing of certain upgrades and installations must also be considered. Heat meters should, e.g., be changed before the heating season, making sure that calibration laws and meter conformity are considered. Regulatory challenges can also complicate energy management in existing neighbourhoods. In some cases, there may be conflicting regulations at the municipal, regional and government levels, making it difficult to determine the best course of action. Additionally, building codes and regulations can vary widely depending on the age and type of the building, further complicating efforts to improve energy efficiency.

Legal challenges can also arise, in particular, with respect to building ownership and tenant rights. For example, landlords may be hesitant to invest in energy-efficient

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upgrades if they are unsure whether they will be able to pass on the costs to tenants. Conversely, tenants may resist changes that require them to pay more for utilities even if those changes ultimately lead to lower overall costs (Inês et al., 2020).

Despite these challenges, neighbourhood management can take several steps to improve energy management in existing buildings. These might include conducting energy audits to identify areas where improvements can be made, leveraging financing programs to offset the costs of upgrades, and working with tenants and landlords to find mutually beneficial solutions. By addressing these challenges, neighbourhoods can improve energy efficiency, reduce costs, and contribute to a more sustainable future.

It is very important to engage and communicate with the tenants. Many energy management and energy saving measures can be further enhanced by adjustments to behaviours or habits. It is important to discuss these with your tenants and to encourage them to take an interest and become actively involved in the process. Tenants should have access to information regarding current consumption patterns, and future goals should be set.

In existing structures, the upgrading of hardware is sometimes hindered by having to enter a rental space, or it may be structurally challenging to reach. Arrangements need to be made for access. An advantage of installing the new intelligent hardware, however, is that, due to their remote reading capabilities, these spaces have to be accessed far less frequently. If tenants are properly informed about the plans from the very beginning and their advantages are communicated, they are more likely to cooperate on access.

Within existing structures with diverse tenant bases, it is important to acknowledge that some tenants may be less competent with technology, and some may not trust it. It is important to respect these individuals and to practice patience. It might be worthwhile to offer additional or individualised one-on-one training or familiarisation options to increase their confidence in the system.

An important consideration - and one that may vary from country to country - concerns the laws on data protection. It is important to research these laws thoroughly and to apply them. Although the collection of data and the visual representation of the energy flow and usage is an important component in engaging, informing and encouraging the community, it must be done in a way that does not violate privacy laws. The potential for cyberattacks should also be examined and measures need to be taken to prevent them. For older sites, like the Baumwollspinnerei, monument protection rules might also have to be taken into account in planning, e.g., the installation of special sensor equipment which is visible from the outside. For the entire VPP, LSW made sure that the entire system runs on the digital kubernetes

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environment in which all applications and services are executed in different docker containers. This serves as an additional safety layer for the the VPP.

3.2.2 Demand response – challenges for the prediction of consumer behaviour

Motivation

As a key element for the operation of the virtual power plant (VPP), the predicted electricity demand is of central importance for the virtual energy community. However, with increasing load-side flexibility and consumer sensitivity to changing electricity consumption patterns, electricity demand is bound to become more heterogeneous throughout the membership body of the energy community. Yet, it becomes increasingly important for municipal utilities to schedule their assets towards expected electricity consumption. Thus, the optimal prediction of consumer behaviour with regard to the electricity consumption patterns is a crucial problem in the operation of a virtual energy community.

The LWB (Leipziger Wohnungs- und Baugesellschaft) and the SPARCs application are designed to inform the user about their thermal energy consumption and motivate them to reduce their thermal energy consumption through a comparison mechanism.

Influences on consumption behaviour

Household electricity consumption can be roughly broken down into two components: unshiftable load and flexible load. Whereas, in this context, an unshiftable load is understood as appliances that can only adapt their consumption profile at great cost, a fraction of flexible loads can be shifted (or even curbed) for several hours without a huge reduction in comfort or operational parameters, thus indicating potential for influencing the electricity consumption pattern overall.

However, the willingness to shift electricity consumption is not a fixed fraction of consumption, but depends on personality and context (Shen et al., 2020) , device, time of day, seasonality and further factors. Thus, it is a heterogeneous and context-dependent variable requiring careful and differentiated consideration.

Traditionally, research has focused heavily on individual efficacy and individual behaviour (Fritzsche et al., 2018). However, individuals are always embedded in a social context that influences their values and behaviour patterns. Furthermore, human beings do not always act like individuals but can act collectively in communities; this perspective of collective efficacy is heavily underrepresented in research and constitutes another research gap waiting to be filled (Fritzsche et al., 2018).

Furthermore, attempts to change consumption behaviour are dependent on consumer awareness, knowledge, and experience (or feedback). In this regard, another research gap is seen in the characterisation of behaviour & consumer characteristics for consumption under intervention strategies (Shen et al., 2020). These differ not just individually, but also depend on the intervention strategies used to change electricity

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consumption behaviour. Research in the field thus needs to address the effect of different intervention strategies as well.

Intervention strategies

Intervention strategies can be differentiated into two kinds of strategies: information-based or (semi-) automated. While automation-based strategies use technical infrastructure to communicate incentives and information with rule-based devices or structured user interfaces, information-based approaches focus on promoting energy awareness and individual feedback.

In (Shen et al., 2020), the authors evaluate five intervention strategies that use different channels (such as leaflets & stickers, WeChat and personal consultation) to provide feedback and energy-saving tips to a subset of customers in the sample within a field experiment directed at understanding the intertwined relationship between interventions, personality and energy saving potentials.

In (Utz et al., 2022), the authors develop a rule-based customer loyalty programme to incentivise household energy consumption in times of a high share of renewable energy in the energy grid. The system further allows the addition of different metrics important for activating energy asset flexibility. Through this, consumers can formalise their preferences. Within this system, the green electricity index or other indices serve as the source of information that is automatically disseminated with the households and formalised into action through the consumer-set rules.

Techniques

Techniques used for the optimal prediction of electricity consumption are, independent of the use case, generally based on well-known statistical methods that are also applied in other industries (Bishop, 2006). These include:

- traditional machine learning techniques, such multiple linear regression (MLR), decision trees, ANNs (artificial neutral networks), SVR (secure vector routing), back-propagation neutral networks, radial basis function NN (neutral network), general regression NN (general regression neutral networks) that are used to model and forecast consumption,
- Monte Carlo-based methods to simulate the household profiles and the influence of personality traits on intervention strategies or modelling occupancy-based consumption prediction (in accordance with Markov chains),
- Markov stochastic models for behaviour change under interventions or occupancy-based consumption prediction modelling (combined with Monte Carlo methods),
- top-down statistical methods to understand the effectiveness of feedback intervention or multiple linear regression for the impact of demographics on energy saving (together with the principal component analysis),

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- support vector regression for consumption prediction under different intervention strategies, in order to deal with complex, non-linear relationships and to achieve high reliability for small samples,
- bottom-up analysis to model energy-use feedback,
- differential evolution, particle swarm optimisation or other hybrid algorithms for selecting parameters of methods mentioned above.

Approach

The approach for the prediction of household flexibilities and their optimal consumption within the project is fivefold:

- investigation and application of energy consumption prediction methods used for the optimal prediction of household consumption,
- investigation of household characteristics and values, as well as individual and collective effectiveness (together with the social psychology group of Leipzig University),
- investigation of household willingness to use energy monitoring technology and incentive schemes based on the smart plug (together with Stadtwerke Leipzig),
- investigation of household willingness to use household flexibilities and required incentive structure (together with Suite 5) and
- interactive simulation-based operation of flexible household assets (LabChain, Johanning et al., 2020).

Investigation of household characteristics and values, as well as individual and collective effectiveness

Within the project, the social psychology group involved in the SPARCS project designs, conducts, and evaluates three survey samples with the tenants of the model districts. This approach aims to apply the results from the surveys to the optimal prediction of energy consumption and flexibility usage behaviour of the investigated customers. As noted above, household energy consumption behaviour is very heterogeneous and personality- as well as context-dependent. This approach aims to provide information on the structure of the groups and characterisation of the investigated household. Special attention is paid to the concept of 'collective efficacy', as discussed in Fritzsche et al., (2018).

Investigation of households' willingness to use energy monitoring technology and incentive schemes based on the green plug

Within the SPARCS projects, Stadtwerke Leipzig have developed a green electricity plug that allows for device-specific monitoring and rule-based operation of the plug - in order for households to adapt their electricity consumption. In Utz et al. (2022) we

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developed a consumer loyalty programme following a similar concept. Within the article, the artifact was evaluated with a limited set of users who did not represent households. This approach will expand on the work done in Utz et al. (2022), adapt it to the concept of green power plugs and evaluate the artifact with the users of the plugs in the model district (Dunckerviertel). This work would be done in cooperation with Stadtwerke Leipzig.

Investigation of households' willingness to use household flexibilities and required incentive structure

As mentioned above, the design of incentive structures requires careful consideration and a solid empirical basis. To this end, we have developed a concept for an app to investigate interventions for leveraging household flexibility and energy saving that is implemented by our partner, Suite 5.
The app generates different scenarios from a set of household assets, temporal perspective (immediately, intraday (later on the same day), day ahead (device usage for the next day)), consequence (direction of the respective behaviour) and motivation to engage in consumption alteration behaviour. The scenarios are then applied in a vignette (Shen et al., 2020)] in order to derive the incentive structure necessary to leverage the intention to save energy or use it more flexibly.

Together with the data acquired by the social psychology group of Leipzig University, these data could be segmented into different consumer types that would allow for a more differentiated picture of the flexibility potential derived from the numerical optimisation, provide information on the incentive function and the strength of collective efficacy and communal understanding of the energy community.

Interactive simulation-based operation of flexible household assets

In a former project at the Chair of Energy Management and Sustainability (Institute for Infrastructure and Resource Management, Leipzig University), we developed an interactive energy economics lab in the form of a simulation for the context of peer-to-peer electricity trading (Johanning et al., 2020). In this setting, experiment participants could operate their assets and trade electricity with one another or third parties. This research infrastructure could be adopted for the context of household flexibility use and experiments could be run with members of the energy community to investigate how they react to incentives and interaction with one another in a controlled environment.

This approach is similar to the investigation of household willingness to use household flexibilities and the required incentive structure through vignettes; however, instead of sporadic sampling of isolated data points, complete time series can be recorded throughout the duration of the experiment. Focus group-based evaluation of the experiments can further enrich the understanding of the motivations and perceptions

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of the experiment participants, giving a more complete picture of the incentive structures and contextual, personal and collective aspects of energy flexibility.

3.1.1 Interoperability of the virtual community with blockchain-based services

The Leipzig virtual power plant has been subject to numerous challenges and barriers. Among the conventional and known issues (e.g., standardisation of interfaces, legacy system, data access rights, limitations of throughput), the use cases involving peer-to-peer energy (P2P) trade and blockchain were of specific concern. While all these cases have been tested, the business case extension is not viable due to regulatory and legal barriers.

For instance, from the perspective of owners of small assets: Article 5 of the German Energy Industry Act (EnWG) sets out the requirement for energy trading to be conducted by authorised companies. This requirement can be seen as a barrier to P2P energy trading and blockchain use cases as it limits the ability of individuals to engage in direct energy transactions without intermediaries. The requirement for authorisation may limit the potential for P2P energy trading, as it creates a barrier for individuals to participate in these types of transactions. Additionally, blockchain technology offers new possibilities for secure and transparent energy trading, but these opportunities may be limited by the need for authorised companies to participate in such transactions.

Regarding the double selling issue: Article 80 of the German Renewable Energy Sources Act (EEG) sets out the rules for the feed-in and priority dispatch of electricity generated from renewable sources. One aspect of this section concerns the prohibition of double selling, which prevents small, distributed energy resources (DERs) from participating in local markets. The prohibition of double selling means that electricity generated by small DERs, such as rooftop photovoltaic (PV) systems, cannot be sold twice to different parties. This restriction makes it difficult for small DERs to participate in local energy markets, as it limits their ability to sell surplus energy to others. The electricity must be supported by the EEG and fed into the grid. The prohibition of double selling can be seen as a barrier for small DERs to participate in local energy markets, as it restricts the potential revenue streams for these systems. This, in turn, may discourage investment in small DERs and limit the growth of decentralised energy production.

For the context of energy taxation: Article 9 of the German Electricity Tax Act (StromStG) imposes a tax on the generation, transmission, and distribution of electricity. This tax applies to all electricity transactions, including local P2P energy trades. The taxation of local P2P energy trading might reduce incentives for individuals to engage in these transactions, as it increases the cost of energy for both the buyer and the seller. This increase in cost can make P2P energy trading less attractive, as it reduces the potential financial benefits of such transactions. Additionally, the tax on local P2P energy trading can limit the growth of decentralised energy systems, as it discourages investment in small-scale renewable energy production and energy

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efficiency measures. This is because the tax reduces the potential financial returns from such investments, making them less attractive for individuals and companies.

Regarding different balancing groups: Article 26 of the German Electricity Market Regulation (StromNZV) sets out the rules for the balancing of electricity supply and demand in the German electricity market. One issue with regard to P2P energy trading concerns the lack of clarity in how P2P transactions should be treated in different balancing groups. Balancing groups are responsible for ensuring that the electricity supply and demand in their respective areas are balanced in real time. However, the legal status of P2P energy trades with regard to different balancing groups is unclear, as the current regulations were not designed with P2P transactions in mind. This lack of clarity can create uncertainties for participants in P2P energy trades, as it is not clear which balancing group is responsible for ensuring the balancing of electricity supply and demand in P2P transactions. This can make it difficult for P2P energy trading to be implemented in practice and limit the growth of decentralised energy systems.

The issue of immutability of many blockchain systems: Article 20 of the General Data Protection Regulation (GDPR) sets out the rights of individuals regarding their personal data. One issue with regard to the use of blockchain technology for P2P energy trading is the lack of user data portability due to the immutability of the blockchain. The immutability of the blockchain means that, once data has been written to the blockchain, it cannot be altered or deleted. This is a key feature of blockchain technology which provides security and reliability, but it also creates challenges for data portability. Under the GDPR, individuals have the right to data portability, which means that they have the right to receive their personal data in a structured, commonly used, and machine-readable format, and to transmit such data to another controller without hindrance. However, the immutability of the blockchain makes it difficult to meet this requirement, as it is not possible to alter or delete personal data once it has been written to the blockchain.

To overcome these barriers, the LSW SPARCS team has discussed potential strategies for future projects. One approach is to lobby for changes in German and EU legislation that would enable P2P energy trading and blockchain use cases. This could involve engaging with lawmakers and industry stakeholders to raise awareness of the benefits of these technologies and to encourage the development of more supportive regulatory frameworks. Another strategy is to identify and collaborate with companies that are willing to participate in specific P2P energy trading and blockchain use cases. This could involve negotiating clear agreements that would enable such transactions to take place within the existing legal framework. It may also be worth exploring alternative business models that do not rely on P2P energy trading or blockchain technology. For example, this could involve developing solutions that leverage existing authorized companies, such as LSW, or adopting a more centralized approach to energy trading. In addition, there is potential for developing new technologies that could help overcome some of the legal barriers. For instance, a blockchain-based system that is specifically designed to comply with regulations and address data

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portability issues could be developed. Finally, working with legal experts who specialize in blockchain energy trade in the German jurisdiction may be helpful as they can provide guidance on how to mitigate the legal barriers. Their expertise could prove invaluable in navigating the complex legal landscape and identifying ways to achieve compliance with relevant regulations.

3.2 T4.4 E-mobility integration: On the way to green energy (LSW, FHG, CEN)

Perspective from CEN / Baumwollspinnerei:

As a former large-scale industrial area, the Baumwollspinnerei in Leipzig, is a prime example of how access to electric charging points can be given to a diverse tenant base to pave the way for the future of mobility. A detailed site inspection comprising technical conditions and the power distribution network is essential. The solar plant is supplemented by a storage unit in order to supply sustainable energy to the charging station in times when this variable energy source is not available. The combined system is supported by a software solution that automates the optimal energy flows.

For the development of a successful e-mobility system in an existing network, such as this one, you need a comprehensive information base of the existing network with as many large producers and consumers as possible. This needs to be very thorough to avoid grid congestion/overload. A digitalised load management system is needed to sustain grid stability if several charging columns are planned. This is the target state in the future.

In addition to the charging stations discussed above, CEN has installed innovative bidirectional charging stations at the Baumwollspinnerei. The concept of bidirectional charging offers great value to grid stability. Vehicles are not only selectively charged at times when this is favourable to the power generation capacity but can also be discharged feeding power back to the grid when there is an imbalance between generation and consumption. As a result, the battery in the vehicle acts as an additional storage system within the microgrid and combined with intelligent software, it stabilises the grid.

As bidirectional charging is a fairly new and innovative concept, there are many challenges that need to be overcome. The digital communication of the interface between the car and the charging station needs to be compatible. In Europe, a standard has not yet been established for this. A legally secure billing model also needs

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to be created for both the charging and discharging of the battery, and the wear and tear on the battery needs to be considered in the model.

In this case, CEN collaborated with BMW in the production of a prototype car and the acquisition of the compatible wall box, which was developed by KOSTAL (see for instance report D4.5).

LSW perspective:

The interoperability of electric mobility elements, such as electric vehicles and other users, assets and platforms within the different layers of smart city systems, is becoming increasingly relevant in today's world. People become more aware of the environmental impact of traditional vehicles. Electric vehicles offer several advantages over conventional vehicles, including reduced greenhouse gas emissions, lower operating costs, and low noise pollution. This has led to a rise in demand for electric vehicles, which is expected to continue to grow in the coming years. Therefore, integrating these vehicles into energy platform systems, such as the Leipzig virtual power plant, poses a challenge on multiple technical levels.

The aim of the SPARCS fleet management task was to help improve the Leipzig charging infrastructure by upgrading it to intelligent charging and enable future use cases through it. At the start of the project, LSW operated about 200 public charging points at over 80 locations and aimed to enhance the existing network of public charging infrastructure with intelligent charging. Throughout the SPARCS project, LSW built additional stations, reaching a total of 454 charging points by the end of 2022. This enabled us to meet the increasing demand for electric mobility and further promote the adoption of sustainable transportation. The task involved developing the rollout process for the intelligent design of the stations, and integration into the existing technical framework for publicly available charging. This permitted the optimisation of the charging infrastructure utilisation, e.g., by enabling fleet management and a reservation function for charging stations. Additionally, it enables grid-resilient charging, allowing for the implementation of new business models for electric mobility. To implement intelligent charging, we first developed possible use cases in coordination with the IT, operations and market department and analysed the available information from the charging infrastructure. We designed the specifications for the charging stations and worked with the charging station manufacturer and e-mobility IT service providers. We then started developing our own back-end based on the Open Charge Point Protocol (OCPP), a communication protocol that enables remote management and monitoring of charging stations, and balancing the load on the power grid by remotely starting and stopping charging sessions.

We procured charging stations that are compatible with OCPP 1.6. The charging stations were installed in strategic locations in Leipzig to increase the operational

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efficiency of the charging infrastructure. We then integrated the charging stations with our own OCCP back-end / Central Management System (CMS) to manage and monitor the stations. The CMS enables remote management and monitoring of the charging stations from a central location.
The CMS is used to dynamically manage the demand for electricity from the charging infrastructure. This is achieved by remotely starting and stopping charging sessions. The CMS receives real-time information about the load on the power grid and uses this information to balance the load. During periods of high demand, the CMS can provide a signal to EV owners to adjust their charging behaviour. By staggering charging times or pausing charging sessions during these critical times, the risk of blackouts and brownouts can be reduced.

We have further developed a mobile application (Leipziger App) that directly connects the end-user and the Central Management System (CMS). The app lays the foundation to enable easy access to the intelligent charging functions of the OCCP-based CMS in a user-friendly way, especially for future business cases. The mobile app provides a convenient way for end-users to remotely monitor and manage their EV charging sessions. Users can view their charging history, check the status of their charging session, and receive notifications when their vehicle is fully charged. Additionally, the app allows users to schedule charging sessions and receive alerts if the charging station is out of service or not available. This approach eases the use of e-mobility in Leipzig, as it safeguards easy access to the charging infrastructure and provides a seamless experience for users. The mobile app is designed to be user-friendly and accessible to a wide range of users, regardless of their technical expertise. The conceptualisation of the mobile app involved defining the app's requirements, functionality, and design together with the product/market and operations departments and IT, as well as external app developers. The app was tested to ensure that it met the defined requirements and functionality. The testing process involved different stages, including functional testing, performance testing, and security testing. It was tested on different devices and on both iOS and Android. The implementation involved designing the final user interface and integrating the app with the OCCP-based CMS.
The CMS has been used to develop a demo showcase for intelligent fleet management. A dashboard has been created to integrate all charging functions into the fleet management context, allowing us to control OCCP functions of all charging IDs connected to LSW-owned charging stations or wall boxes managed by LSW. In the demo showcase, a number of vehicles are selected, and their current online status is checked. Based on the status of the distribution grid and the potential threat to its resilience, the charging processes of the vehicles are stopped. Currently, this test case is only carried out with LSW-owned vehicles, but this function can be performed for every customer.

The impact of these tasks is twofold: In regard to the Leipziger App and charging infrastructure, we have experienced a substantial increase in charging station

utilisation and positive feedback on the app. We were able to built value-added services on top of the intelligent charging infrastructure. For instance, the new CMS enables us to handle charging protocols and remuneration of public charging points and LSW-managed wall boxes in private homes the same way. This allows for the wide-spread integration of e-mobility users in the city's mobility ecosystem. Customers can charge their vehicle at home and later at work using the same app. This substantially simplifies their overview of billing and vehicle utilisation. Furthermore, we provide a service that directly creates tax reports for charging company fleet vehicles. This is relevant in countries like Germany, where private use and charging of company vehicles has impact on personal taxation. By using the newly developed charging CMS, the entire process of e-mobility use is therefore streamlined for the user.
Regarding the aims to foster grid resilience, we have just developed the foundation for future utilisation. As of now, the impact of stopping loads of vehicles currently in charging processes is not significant for the operation of the distribution grid. The reason for that is the still relatively low number of electric vehicles compared to fossil-fuel-based vehicles, the adequately designed grid structure, and the currently well predictable load pattern of charging processes. However, as the relevance of electric vehicles increases in the future, these variables will change. For this likely scenario, SPARCS has provided the foundation for business models that provide the necessary flexibility to address these challenges.

The product, operations and IT departments are working on business models to ensure remuneration for this function. The back-end and the fleet management dashboard provide an innovative solution for ensuring the resilience of the power distribution grid while also enabling the intelligent management of company vehicles. In this process, we have discovered notable implications for replication:
Regarding one of the early proposals to use bi-directional instead of intelligent charging: The overall aim was the realisation of demand-side management for urban e-mobility, i.e. enabling the digital platform to adjust the EV charging process in response to signals from the power grid. The most pressing issue was that the car manufacturing industry has, so far, not provided a sufficient number of electric vehicles supporting bi-directional charging. Since the number of supported vehicles in the distribution grid is crucial for the utility of this measure, other demand response mechanisms are, at this point, more suitable for dynamic grid control. Therefore, the following changes were undertaken: In order to implement the most effective tools for demand-side management Stadtwerke Leipzig focuses on the installation of its back-end architecture that provides intelligent charging of the EV. This includes remote starting and stopping, shifting and deferring of loads in response to signals from the grid or the market. For the replication of intelligent charging use cases, it is notable that circumstances in the car manufacturing industry have not changed and right now, bi-directional charging is only a prototype-level topic and not applicable to current business cases.

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The development of a product based on the intelligent charging project has both advantages and disadvantages. While the OCCP-based CMS and the fleet management dashboard demonstrate innovative solutions for ensuring the resilience of the power distribution grid and efficient management of charging infrastructure, are not yet widely adopted. At present, there are not enough electric vehicles on the roads to pose a significant threat to grid resilience, and the predictable charging behaviour of existing electric vehicles does not present a major problem for the grid. Therefore, as of now, it is unlikely that products based on intelligent charging and vehicle-based demand response would be financially stable. However, from the perspective of a utility that also meets public requirements, we believe that, on a city-level, it is important to prepare for future circumstances which might require a more robust approach to grid resilience and charging infrastructure management. As electric vehicle adoption grows and the demand for energy becomes more difficult to predict, it is crucial that other cities start replicating this approach of developing information systems as a foundation for intelligent charging business models. By doing so, they can better position themselves for future growth and ensure that they are ready to take advantage of emerging opportunities in the electric vehicle market. We will continue to monitor the market and work closely with stakeholders to evaluate the feasibility of the business models focused on intelligent fleet management.

3.3 T4.5 Planning of energy-positive communities (LPZ)

The SPARCS team of the city of Leipzig is working on a standard approach to climate-just district development.

To this end, the SPARCS team is conducting a series of workshops with city units involved in district development, and it is working on bringing all relevant energy planning data into one data platform.

Standard model (L20)

The workshop series revealed that energetic district development shall be carried out in the current framework of district development with the help of an energetic district development programme by the German Bank for Reconstruction (Kreditanstalt für Wiederaufbau, KFW), programme no. 432.

Within this framework, the possibility to optimally use the entire discovered energetic potential, e.g., with the help of a virtual power plant, would be ideal. Therefore, both technical requirements need to be formulated (interoperability requirements), business cases designed (profit option for profitable assets, and environmental option for cost-neutral assets) and regulatory frameworks defined (possible contracts).

Data on the Urban Data Platform, working title "Leipzig Energy Atlas" (L19)

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For energetic district refurbishment concepts, the districts first need to be chosen (1), then analysed for their state (2) and their potentials (3). Afterwards, measures need to be elaborated (4), chosen (6) and carried out (6), and, finally, monitored (7). To facilitate steps 1-3, and to enable various city actors to implement well-informed energy planning, the city of Leipzig is currently elaborating a joint display of energy related data and plans within the existing GIS framework. This will facilitate analyses and allow for more time for action development and implementation.

The data will be developed further into digital twin applications within the context of the CUT Project (Connected Urban Twins). This will allow more detailed analyses and simulations.

Connection to interoperability

A VPP, as included as a measure in SECAP 2030, and interoperability standards would be central instruments to systematically integrate renewable energies assets and flexible loads detected with the help of systematic district development concepts. Under the 2019 Climate Action Emergency programme Leipzig is required to develop, at least, three districts a year. This measure is underlined by SECAP 2030 and the 2023-24 implementation programme.

It has yet to be shown in the replication and upscaling concepts whether there is a cost or environmental benefit in comparison to “plain” integration into the electricity grid, as well as to the concrete design of the technical interoperability standards, and the contract design.

It can be expected that some renewable energies assets will only connect to the VPP if there is a clear economic benefit. If LSW were to pay a small fee for using electricity from Leipzig’s roofs, this could open up access to these, tapping into the huge potential identified in the solar potential cadastre. This would save other spaces from renewable development.
However, some not-for-profit market actors will probably even connect to the VPP if this is cost-neutral provided a clear environmental benefit can be shown. If there is an environmental benefit, these should also be considered in the relevant contracts.

Further linking heat and electricity production within municipal boundaries with heat storage (as by LSW, or aquifers), and with e-vehicle charging, is an excellent option. In February 2023, the EU decided to ban internal combustion vehicles from 2035. Hence, from 2035 on, only electric cars will be available, so it is even more important to plan for sufficient charging points and for the bidirectional use of the future car batteries. A further rolled-out VPP will be an excellent asset to efficiently supplement this.

3.3.1 T4.6 Community support for energy transformation in the district (SEE, LSW, LPZ)

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This paragraph is divided in two parts. The first section focuses on what incentives and motivation can be set to shape citizens' initiatives for a sustainable energy transition. The second section deals with two practical application examples. The SPARCS App and the Smart Plugs. The first topic examines the question:

How can citizens become involved in the virtual power plant?

Finding an appealing, concrete topic:

The most difficult challenge is finding a topic that really means something to citizens. Are people interested in the topic I am proposing? Do they need answers in this field? Do they have problems that need to be solved concerning the main topic? We must not forget that more and more - often commercial - competitors with different offers and bigger budgets, work on the same target group and might divert their attention. So the question is: Is this topic tangible and concrete? For instance: Rising energy prices have more of an impact than "saving polar bears".

Identifying and defining the right target group and using appropriate language:

For example, in terms of urban transformation, it is important to know whether people sleep in a certain neighbourhood or whether they work and live there and are more motivated to contribute to the transformation. Are they tenants or homeowners? It is very important to look at things from the perspective of those concerned. In the transformation process, you can communicate and reach people more easily if you use tools adapted to their requirements and level of awareness. What do people lose and what do they gain from change? How much are they affected by the planned transformation?

Using different marketing strategies, good networking and eye-catchers

The use of different marketing strategies can support this process: It is, therefore, useful to publicise a theme or an event in different print and digital channels. People become involved more easily after direct contact is established. As a result, people are then more motivated to actively contribute to the transformation. In our case, the organisation of the drawing competition and the Table-DIPAS were good examples of this.

Creating events and providing information:

Accompany and involve people in their process of becoming aware of transformations and provide them with new information about these. Use supplementary abstract notions and specific studies with real examples and best practices; these have a better impact than mere theory.

Setting good examples:

During an event, it is very important to set a good example. For instance, my neighbour has installed a photovoltaic system on his balcony and is very enthusiastic about it. At the same time, it is also very important that we create incentives & present solutions instead of showing fears or losses.

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How can citizens and other community actors in the district become part of an energy transformation technically? What, in their case, needs to be interoperable to enable them to become part of a virtual power plant? First of all, they need to have possibilities to interact in the field of energy. In the context of SPARCS, this was implemented for the residents with the help of two measures:

Smart plugs:

In order to underpin this theoretical content with practical examples, the smart plugs are listed here. LSW customers are to be motivated to adapt their electricity consumption on the basis of a gamification approach. Using an app existing customers can control their consumption and, at times when this is particularly efficient, start up devices that require electricity from home. Points can be collected in the app for energy-sustainable behaviour, which can then be redeemed for rewards. The aim is to use such green products to introduce sustainable behaviour and changes in behaviour. Through such examples, citizens become energy savers and part of a sustainable ecosystem.

SPARCS App:

WSL's other tasks include the development of an app-based application to visualize heat consumption for tenants* in the apartments. This app will help to save energy and optimize heat consumption.

To achieve this, the buildings will be equipped with smart devices, control devices and meters and digitally connected to each other to integrate the buildings and data on a digital platform and build a dynamic energy system. In addition to the heat consumption of the buildings, electricity consumers and the local renewable power generation plants of WSL (Wohnen & Service Leipzig GmbH) will be integrated in cooperation with Stadtwerke Leipzig to create a virtual power plant for a CO2-free energy supply.

On the one hand, the dynamic energy system is to link the information of the building consumption with the generation of the solar thermal system and the electricity generation of the photovoltaic systems of WSL and thus optimize the direct use of CO2-free heat and electricity generation. On the other hand, the system is to optimize the central control of the heating system in the buildings in real time in order to reduce energy and CO2 consumption and to increase the well-being of the tenants*.

Smart sensors and measurement technology have already been tested and selected for this goal and will be installed in the apartments and buildings in the coming months. In addition, suitable platforms for data collection and processing have already been

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analysed and selected, and the central heating systems in the basement will also be digitized.

4. Core results and Outlook

Project reflection - Possibilities and limitations: From application to market-implementing reality:

4.1 Added value from the implementations

When we look back at the huge SPARCS-Project, we see different benefits which we achieved.

Working together with all the different partners gave us the chance to develop our international network. We have learnt how other cities and companies have implemented the smart City approach. We discussed our ideas and tasks within this consortium and got feedback from partners who were dealing with similar topics.

Exchange and knowledge management at an international level was not only a theoretical promise – it was accomplished with workshops and meetings in the smart cities. The hosting partners organised visits to the demonstration sites and discussed their results with the experts from other smart city partners, so that we could see a real transfer.

We did not only have the connection between the international partners, but we also had a connection between practice and science. Together, we worked on the same topics with the goal to develop the city vision 2050. That also means, that we used the chance to build our local network which is a benefit for our daily work.

Without this project, it would be harder to get all the partners together to work on one goal. Here, we were partners - but some of us are also competitors. We needed time to find our roles in the projects and managed this well. In some ways, we will still benefit in our daily work – even as competitors.

On the local level, we focused on working on the city vision 2050 and the achievement of our tasks. With its innovative character, this project gave us the chance to concentrate on innovations. Here, we had room for testing and modifying our actions. Together, we developed a plan for a sustainable and innovative energy supply in different city districts. Renewable energy will play a big role in the future. One of the project goals was to illustrate this – a sustainable and innovative energy system based on renewable energy – to the residents and give them the chance to participate in this process. Besides the energy topic, we also created a joint plan for the digitalisation and the milestones involved. We reached a data platform as a basis for future activities

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and scalable concepts and modules for expanding the digital energy services business. There is still a lot of work to do but now we have created the basis.

4.2 Recommendations for actions in practice

The goal of the Leipzig actions is to demonstrate how many small actions can be used to optimise the flow of energy in a district.

In retrospect, there was a certain period of time between the preparation of the application, awarding of the contract and the start of the project, during which some framework conditions changed or developed further. On the one hand, this plays a role in innovative topics, but also when, for example, the general conditions change. Participation in this EU project left a certain framework for adjustments to the original application. One has to bear in mind that there is a time delay between the application, awarding of the contract and the implementation of the project. This procedure should be retained for future projects and its organisation should be simplified.

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