Development of Scenarios for Modelling of Districts' Energy Supply and Analysis of Interdependencies between Energy and ICT

Fernando Penaherrera
Carl von Ossietzky Universität Oldenburg

Henrik Wagner
Technische Universität Braunschweig

Sarah Fayed
Hochschule Emden/Leer

Oliver Werth
OFFIS

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Fernando Peñaherrera V.[1], Henrik Wagner[2], Sarah Fayed[3], Oliver Werth[4], Stephan Ferenz[5], Jana Gerlach[4], Tobias Lege[6], Annika Ofenloch[1], Thomas Poppinga[7], Catharina Siemer[1], Michael Breitner[4], Bernd Engel[2], Lars Kühl[6], Sebastian Lehnhoff[1], Astrid Nieße[5], Johannes Rolink[3], Sven Rosinger[1], and Frank Schuldt[7]

[1]OFFIS Institute for Information Technology, Oldenburg, Germany
fernandoandres.penaherreravaca@offis.de
[2]Technische Universität Braunschweig, elenia, Brunswick, Germany
[3]University of Applied Sciences Emden/Leer, Emden, Germany
[4]Leibniz University Hanover, Institute of Information Systems Research, Hanover, Germany
[5]University of Oldenburg, Digitalized Energy Systems, Oldenburg, Germany
[6]Ostfalia University of Applied Sciences, Wolfenbüttel, Germany
[7]DLR, Institute of Networked Energy Systems, Oldenburg, Germany

Abstract. The increasing digital transformation in energy supply systems allows greater control and possibilities for performance optimization and efficiency. This is accompanied by increasing complexity of the system, and thus requires the evaluation of interactions between energy and information and communication technologies (ICT) involved. One of the goals of the project "Zukunftslabor Energie" (Future Laboratory "Digitalization Energy") is to analyze these interactions in highly integrated digitalized systems for district energy supply. For this, simulation studies must be conducted to configure flexibilities. A first step is to define appropriate analysis scenarios. Requirements for these scenarios, the related models, and one of the considered scenarios are described in this paper. This allows to discuss the system, its boundaries, its components, and their interactions. Future research requires an analysis and discussion of requirement specifications, data collection and treatment, model construction, model implementation, and model validation.

Keywords: Energy Supply Scenarios, District Energy Supply, Smart-Grids, Digital Transformation of Energy Systems.

1 Introduction

The role of digital transformation in energy supply systems has become increasingly important, as it enables the acquisition, monitoring, communication, analysis, and optimization of relevant measured values, and the (remote) control of (decentralized) energy conversion plants and operating equipment. This allows a more efficient operational management, which adapts to the rapidly changing processes of energy

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economics. A complex integrated energy system, which includes different energy supply and conversion forms such as electricity, heat, or gas, creates on one hand a different kind of flexibility, that allows, for example, a quick and accurate reaction to forecast uncertainties of fluctuating decentralized energy supply. On the other hand, it drastically increases the system complexity, which affects modelling and control in several fields like cost-effectiveness, financial viability, flexibility, technology acceptance, data security, and usability [1].

The aim of the Project "*Zukunftslabor Energie"*[1] is the investigation of interactions in highly integrated ICT- and energy systems for district energy supply (objective 1), and the parallel development of a platform that enables networking of researchers and stakeholders (objective 2) to facilitate the transfer of innovative research results and support further investigations, focusing on the above-mentioned fields in digitalized energy systems.

The topic of this paper refers to the first of five main work-packages within the first objective of the project ZLE, with the central target of research and development of digitalized energy systems. To describe a comprehensive framework of such energy systems, highly integrated application scenarios for three sample districts in Germany are to be defined and thoroughly analyzed. Each scenario represents an objective towards an energy system which is, when compared to a baseline, possibly more efficient, sustainable, economical, securely protected against cyber-attacks, and accepted by stakeholders. Despite of the importance of field and laboratory tests, computer simulations and numerical optimization processes play a major role in the project due to configuration flexibilities and saving of considerable development costs. This reflects the need for conducting simulation studies to analyze the different scenarios.

The first work-package deals with the identification and definition of relevant energy supply scenarios in districts and use cases for the investigation of ICT dependencies. Subsequent work-packages cover the identification and assessment of requirements of relevant models for the simulation and analysis of the defined scenarios, modelling and development of the integrated supply scenarios, systematic experiments, tests and analysis, and finally, processing and publishing of the results. The goal is to develop a modelling framework that includes the demand for heating, transport, and electricity, and considers the trade-offs between energy supply and ICT systems.

This paper focuses on presenting the process of scenario definition. Section 1 provides a short overview of the project research activities. Section 2 summarizes information on modelling of smart energy systems. Section 3 describes the requirements of the energy scenarios for residential districts. Section 4 gives an example and an overview of a scenario to be modelled, and details the components considered for those scenarios and which elements are included. Conclusions in Section 5 are oriented to the next steps of research activities.

[1] zdin.de/zukunftslabore. Last visited on 28/01/2021.

2 Modelling Smart Energy Systems for Districts

The overall motivation when developing scenarios for district energy systems is the cost-efficient application of renewable energy sources while minimizing greenhouse emissions [2]. In the case of the districts electrical energy supply, decreasing costs for photovoltaic systems and declining feed-in tariffs are turning the self-consumption of the photovoltaic electricity lucrative [3]. Such a decentralized expansion of renewable energy sources could also be economically favorable due to lower grid expansion costs than in the centralized cases [10]. In addition, the storage of electrical energy has become more attractive due to subsidies and decreasing costs of battery storage systems [4]. Combinations with electrolyzers indicate a promising attempt to process all the produced renewable energy. Heat supplied through heat pumps is also gaining importance in new buildings or newly build districts [3]. Moreover, districts' low voltage grids face new challenges due to the increasing adoption of electric vehicles and charging processes taking place in households [5].

The integration of ICT systems in the energy system allows a more flexible operation and facilitates the coupling of renewable energy sources [6]. The ICTs enable an energy management system which supports the control functions needed to regulate energy flows and to participate in energy trading markets [7]. ICT systems in the energy sector relate to all applications which simulate a district as a spatial framework and the district's energy system behavior. The goals of such a system are: to study and control the application of energy strategies and measures; to monitor energy generation, supply, transmission, and consumption; or to manage the demand side. This aims to improve the energy system performance [8]. The analysis and optimization of ICT solutions are gaining importance in the energy sector due to the fast transformations of energy systems [9]. Smart grids allow communication for efficient management and resource control, and micro grids are designed to effectively integrate local distribution and generation, and to operate in both non-autonomous (grid-connected) and autonomous (stand-alone) modes [10]. Several studies review different ICT and network infrastructures for micro grid operation and control [11]. Flexibility of implementation, installation costs, efficiency of communication range, security, availability, and scalability belong to the most important considerations for implementing the ICT layer. Several alternatives for communication and control methods offer higher flexibility and reliability. As an example, a multi-agent system decentralized approach considering long term optimization to solve the scheduling of distributed energy resources is presented in [12].

The combined simulation of energy systems and communication networks has attracted attention due to rising interest in smart grid from governments, industry and academia [13]. Parts of large systems are typically modelled and simulated by different techniques and tools [14]. A combined simulation of energy systems and ICT infrastructure can be achieved using a co-simulation [13]. Co-simulations allow the consideration of interdisciplinary dynamic interactions of complex components and systems. They couple independent simulation tools representing different parts of the system [15]. The objective is to develop a model which is able to share inputs among various simulation tools and link outputs to the inputs of a second tool [16].

Individual simulators are independent black boxes that need an orchestrator to couple them. It controls how the simulated time progresses in each simulator and moves data from outputs to inputs according to a scenario [14]. In the context of smart grid co-simulation, a co-simulator would consist of a specialized communication network simulator (e.g. OMNeT++) and a specialized power system simulator (e.g. OpenDSS, pandapower). An example of such an orchestrator is Mosaik[2], a modular smart grid simulation framework supporting automatic composition of existing, heterogeneous simulation models for the evaluation of control strategies for heterogeneous distributed energy resources and loads [13]. Setting up a co-simulation requires therefore the definition of the objectives and the preparation of scenarios [17].

3 Requirements of the Energy Scenarios for Residential Districts

3.1 Modelling objectives

One of the objectives of the is the study of interactions in highly integrated energy and ICT systems in districts. Interconnections between the electricity sector and heat, power, or gas sector increase the system flexibility. The integration of renewable energy sources introduces new challenges to the distribution grid [18].

The central technical research question is the identification and modelling of complex interactions between ICT and energy systems. This is to be achieved through identification and modelling of complex interactions between ICT and energy systems, and the investigation of (cyber-)resilience in districts. The influence of electrical measurements, monitoring and automation systems on the efficiency, optimality, and stability of (decentralized) energy supply concepts, including technology acceptance, is to be specifically investigated. This shall include dynamic scenarios with temporary reduced availability of ICT systems, either due to capacity utilization, technical failures, or systematic attacks. The ICT systems allow a flexible operation of the facilities that enables optimization of parameters such as cost, self-consumption, or greenhouse gas (GHG) emissions. The different technological components are to be integrated in simulations to evaluate their interactions.

The simulations require an application-oriented approach. Scenarios aim to investigate the influence of monitoring technologies on the efficiency and stability of the system, autonomous power optimization, energy optimization, and marketing of flexibilities to third parties.

3.2 Model requirements

The simulations require models representing real systems from selected residential districts [19]. It is first required to define what is going to be modelled and how this could be achieved, independently of the used software [20]. This should define the

[2] https://mosaik.offis.de/. Last visited on 28/01/2021.

model boundaries, the components, their activities, relations, and resources, as well as inputs and outputs [21]. A bottom-up modelling approach is used. Models are built up from extensive data on energy use and energy demand [22]. Engineering models make use of physical and technological characteristics of individual components to compute their performance. These models have the highest level of flexibility in evaluating technological developments and energy efficiency scenarios [22].

A systems-wide perspective that takes into consideration the trade-offs between different components of the energy system is needed [23]. To describe an energy system in a district, the following components need to be described [24]:

a) System boundaries:

The considered systems shall encompass the energy supply and use within an energy district, from the connection points to the local energy grids, to the energy use by the residents and facilities, also including local energy supply and local energy networks, and the energy managing and monitoring systems for the energy supply and use. Centralized external energy generation coupled to the energy system is also considered.

b) Components:

To investigate the interactions between ICT and energy systems, the following components are to be considered:

- Energy grids, such as electrical or gas grids.
- District energy supply outside of the residential district (sector coupling).
- District distribution grids, energy supply and storage.
- Buildings distribution grids, energy supply, and storage.
- Final users, including their energy demand for heating, cooling, electricity and transport [23].
- External data sources and energy markets.
- Centralized and decentralized Energy Management Systems (EMS), including monitoring, controlling and supervision devices.

c) Interactions

The flows of energy and data between the components need to be considered. This allows evaluating energy transport, transformations, losses, and final energy use. The data flows for monitoring and controlling of the system by the Energy Managing Systems (EMS) allow the evaluation of the interactions between the ICT and the energy systems.

d) Inputs and outputs

These relations between data and energy flows allow to evaluate the behavioral dependencies between the energy and the ICT systems, and the impact of the different scenarios on performance metrics. This requires a data input that considers meteorological conditions, component physical properties, energy demand time-series, and development of scenarios for different cases of ICT performance. Occupants demographic profiles allow assessing energy demand profiles and studying technology acceptance for both energy supply and ICT components.

4 Scenario Overview

This section presents an exemplary scenario of an energy supply system in a district, which will be modeled within the research activities of the project. The underlying district called “Rüsdorfer Kamp” belongs to the city of Heide in the district of Dithmarschen, Schleswig-Holstein, the northernmost state of Germany. The concept of the district energy supply system was developed by the Steinbeis-Innovationszentrum energie+ (siz energie+)[3] during the research project QUARREE100[4]. Responsible for the overall project coordination are the Development Agency Region Heide[5] and the Advanced Energy Systems Institute[6]. The project runs from 2018 to 2022. QUARRE100 focuses on the conversion, storage, control, and distribution of renewable energies in the urban district “Rüsdorfer Kamp”. This urban district is considered due to its representative building stock and its mixed-use – private and commercial – which allows a good transferability to other urban districts. Specific requirements for the energy supply system the research project QUARREE100 are, among others:

- **Renewable energies and GHG emissions**: Fully utilize electricity from renewable sources, through the complete integration of renewables, for example, by considering central and decentralized renewable energy sources. Complete avoidance of GHG emissions in the neighborhood in the long term.
- **Resilience and responsiveness**: In case of failures of one or more subsystems of the energy supply system, the remaining system should compensate the failures quickly and flexibly.
- **System usability**: Contribute to the overall goal of making the energy system more flexible. In accordance, the district energy system should provide grid support. This will be achieved by providing an intelligent energy control system in the district.
- **Future mobility**: Another goal is to create interfaces for sustainable mobility using different energy sources such as electricity and hydrogen. For this purpose, in addition to charging stations for electric vehicles, fuel dispensers for hydrogen-based fuel cell drives are to be created as part of a "filling station of the future".

Figure 1 illustrates one scenario. It depicts one design of the energy supply system of the district at “Rüsdorfer Kamp”. In the following, the main components of the district's energy supply system are briefly described:

- **Electrolyzer**: The electrolyzer is required to produce the hydrogen needed for the "refueling station of the future". The hydrogen produced is temporarily stored in a pressurized gas tank.

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[3] Steinbeis-Innovationszentrum energie+, steinbeis.de/de.html. Last visited on 29/11/2020.

[4] QUARREE100, quarree100.de/. Last visited on 29/11/2020.

[5] Entwicklungsagentur Region Heide, region-heide.de/entwicklungsagentur/. Last visited on 29/11/2020.

[6] The Advanced Energy Systems Institute, pse.uni-bremen.de/aes.html. Last visited on 29/11/2020.

- **Heat network and heat pumps**: A separate heat network will be implemented in the district for the heat supply. It will only be temporarily connected to the public grid and is fed by several heat pumps within the district. The heat pumps will provide most of the needed heat energy in the district.
- **Thermal storage**: The thermal heat accumulator has a large capacity and seasonal storage capacity.
- **Combined heat and power (CHP) plant**: The CHP prioritizes heat before power generation and serves to provide heat during peak heat demand.
- **Electric grid**: The electric grid is to be designed as a closed district operating system. Therefore, it is decoupled from the public electric grid. In the shown scenario this is altered due to the desired consideration of flexibility marketing. The sub-station connecting the district grid with the public grid will consist of an adjustable local grid transformer to ensure an active voltage regulation.
- **Photovoltaic system**: The electricity production is completely designed for self-consumption, such as for the heat pumps. The district operator leases the necessary roof areas of the residential and commercial buildings in the neighborhood.
- **Battery storage system**: In addition to the storing of the produced renewable energies it serves to ensure grid stability. Accordingly, it is used for peak-shaving, voltage regulation and the provision of reactive and balancing power. It also provides energy for the heat pumps in the evening.
- **Charging infrastructure for electric vehicles (EV)**: This will be coupled with a charging management system that ensures that the EVs are mainly charged with locally generated renewable energy.

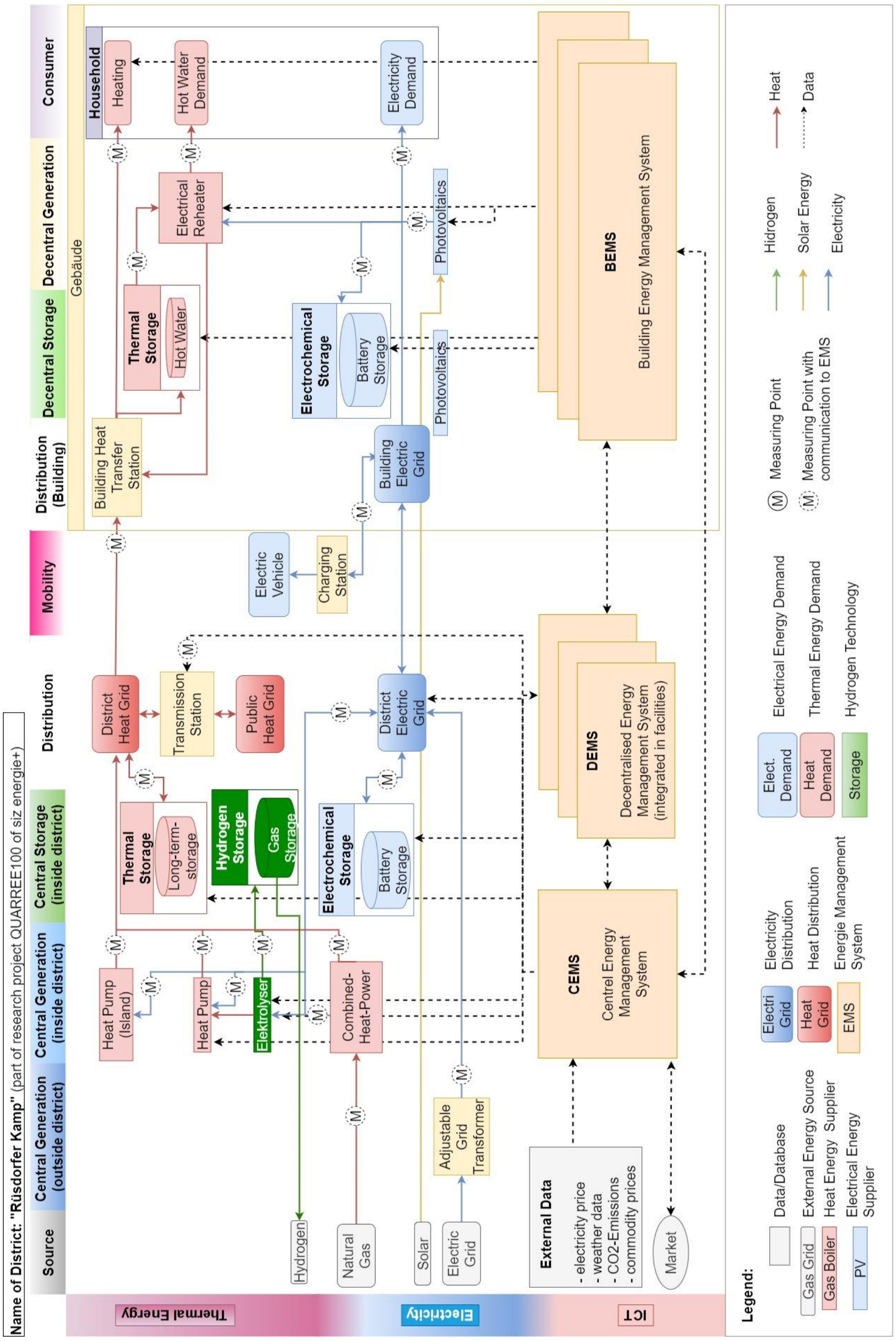

Figure 1. Schematic representation of the developed energy supply scenario for Rüsdorfer Kamp.

5 Conclusions and Future Research Agenda

This paper summarizes the research activities for the investigation of interactions between highly integrated ICT and energy systems for district energy supply. The research goal reflects the requirements of developing simulation studies for the analysis of the interdependencies of ICT end energy devices in digitalized energy systems. To achieve this goal, three residential districts are chosen, and the example scenario Rüsdorfer Kamp district is introduced. This scenario was developed starting with an analysis of the project objectives and research questions and followed by a definition of model requirements. The system boundaries, the components and their interactions are described for the presented scenario.

Future work follows the steps of simulation studies procedures [24]. For this, an analysis of the requirements and interfaces of each of the different model components is the next step to obtain requirement specifications for the models and its components and develop formal models for the scenarios. Furthermore, different types of data, including component behavior and properties, interfaces, energy demand profiles, energy markets data, device communication characteristics, are therefore required to implement and execute models that allow evaluation of these scenarios.

Additionally, to perform simulation of different components and systems, an approach of coupling different simulation tools representing different parts of the overall system is required. Co-simulation has been identified as an efficient and flexible approach that allows consideration of interdisciplinary dynamic interactions [15, 25]. This enables domain-specific components such as power grids or communication networks to be addressed by their modelling tools, to share inputs among these tools, and to link outputs to the inputs of a second tool, so different components can be integrated [16, 26].

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