Preprint

Development of an electricity, heat and mobility concept at district level under consideration of sector coupling for the Lagarde Campus Bamberg

Daniel Then[1,3], daniel.then@stadtwerke-bamberg.de; Stefan Loskarn[1], Jan Kaiser[3], Jan von Appen[3], Tanja Kneiske[3], Sebastian Buchholz[2], Volker Stockinger[2], Mara Münder[4], Astrid Schütz[4]

1 Stadtwerke Bamberg Energy- and Water supply company GmbH
2 BUILD.ING Consultants + Innovators GmbH
3 Fraunhofer Institute for Energy Economics and Energy System Technology IEE, Kassel
4 University of Bamberg

Abstract

The integration of electricity and heating systems as well as a large number of electric vehicles into existing grid infrastructure represents a challenging task for urban grid operators and energy service providers, but also offers flexibility potentials. The conversion process of the former Lagarde barracks in Bamberg depicts a blueprint for development of an integrated energy system. A conceptual design of a multi-energy system for the heat and power supply of a city district of approx. 20 ha. in the middle of already existing urban grid structures is presented. This covers the electrification of the heat generation including a district heating grid, the integration of high penetration of electric vehicles and PV systems, as well as the integration of a thermal storage under consideration of the overall system performance regarding CO_2 emission and costs. The feasibility of a cross-sector implementation within the framework of the ambitious goals from the BMWi's funding context "Wärmenetze 4.0" will be examined. This includes both an analysis of possible energy concepts from a technical and economic point of view, as well as an examination of the non-technical needs and acceptance of future residents and various stakeholders.

1 Background

As a part of the former US Army barracks in the east of Bamberg, the municipality has set a date of completing the urban development of the 20 ha Lagarde barracks by 2035 (see **Figure 1**). The vision is to transform the barracks to a modern city district “Lagarde Campus” with a mixed use.

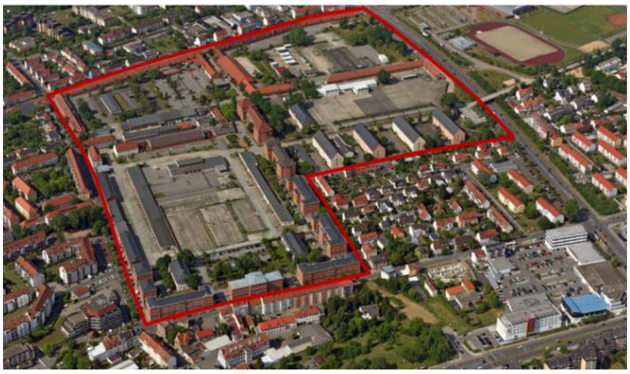

Figure 1 Aerial view of the former Lagarde barracks [1]

Based on a design contest for the city development, a concept for the whole area of the former barracks was established in 2014. The approach covers political aims regarding energy and water supply, mobility as well as digitalisation and of waste and water disposal [1].

The plan forecasts 175,000 m² of net floor space, where 34% is expected to be commercial, 51% residential and a further 15% cultural and community-based. New buildings represent approx. 50% of the total building mass and have to be integrated into the existing building stock. In this way, the core of the area, which is protected as a historical monument, as well as the properties under ensemble protection should be preserved [1]. The central office of the Bavarian judiciary for cybercrime and a digital start-up centre for the region of north-east Bavaria are currently being built on the area and will form the core of an IT quarter.

The Stadtwerke Bamberg as the local service provider are responsible for the operation of the electricity, gas and heat distribution grid, local public transport and parking facilities as well as the broadband communication network, that currently under construction within the city area. So it is the task of the provider, to develop and implement an energy and mobility concept for the city district.

In 2017, a preliminary study was performed to develop a concept. This plan contains the basic technical standards for all buildings, replaces the development plan during development phase and was recorded in a quality manual (see **Figure 2**) [3]. The investigations presented in this paper are based on this concept and represent the results of the feasibility study for the construction of a heating grid under consideration of sector coupling and high amounts of renewable generation.

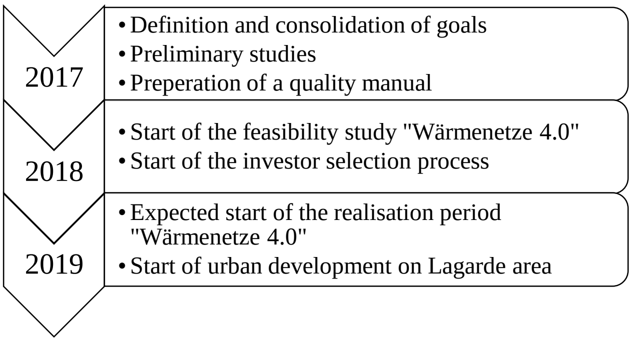

Figure 2: Development schedule

2 Motivation and goals

2.1 Motivation "Lagarde district"

The political key goal of the municipality for the city district is the minimization of the ecological footprint of the inhabitants. In terms of energy supply and mobility, this means looking for low-emission and CO_2-efficient solutions for the overall system by maximising the use of renewable resources.

These abstract goals were formulated as concrete requirements for all possible investors within the quality manual (for a detailed description see [3]). The feasibility study approaches these goals in a holistic cross sectoral approach [4-6].

2.2 Innovations "Lagarde district"

Worldwide various projects are dealing with the development of a smart grid infrastructure or the usage and integration of a high amount of renewable generation into heating and power grids [6-8]. Often those projects focus on technical aspects, like the integration of new assets or the interconnection of assets based on the perspective of energy supply. This project has a more holistic view on the development process in a "real world environment".

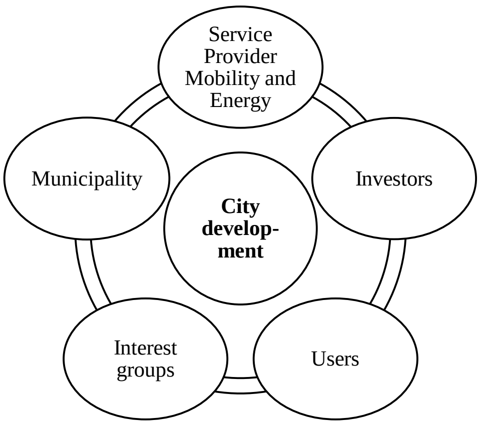

Figure 3: Actors involved in development process, based on [7]

It addresses the development and implementation of an integrated mobility and energy system on technical as well as product level into an existing grid and building infrastructure. Thereby it is important that possible concepts are getting accepted by all actors in the development process and future use (see **Figure 3**). This issue will be faced by analysing the non-technical demands of the future inhabitants and investors as well as the acceptance of the energy- and mobility concepts and services.

The following innovation factors are seen as decisive for this development concept:

- Integrated development and implementation of an electricity, heat and mobility concept
- Development and integration of a smart heating system in existing and new building structure
- Integration of this coupled multi-energy system into existing gas, electricity and heat grid structures
- Investigation and consideration of the acceptance and needs of involved actors

2.3 Goals of the feasibility study

The feasibility study represents one sub step of the whole development process of the city district, with the major goal of the development and implementation a heating system of the 4th generation [2]. This includes the integration of a high amount of renewable on site energy generation as well as data links between intelligent assets (generation, storage and demand units) with the objective of reaching energy reciprocity which means the optimized interaction between all actors in energy system [9].

To achieve a share of renewable energies of over 50% [2], especially in urban areas, it is necessary to mix different local available energy sources from industrial processes and low exergetic environmental sources. To integrate such highly volatile sources flexibility is needed [4-5], which will be delivered by electrifying heat and mobility demand and possibly storage systems. Due to that fact the study itself contains the following parts:

- Analysis of local conditions and constraints
- Analysis of non-technical demands and acceptance
- Examination of power-, heating-, cooling- and mobility demand
- Analysis of potential energy sources, storage potentials
- Examination of potentials for sector coupling
- Techno-economic assessment of supply variants
- Assessment of regulatory aspects
- Development of business models for service providers

In the next sections the methodology and results of selected working packages will be presented.

3 Selected approaches of parts of the study

3.1 Estimation of power, heating and mobility demands

To estimate the heating and cooling demand of every single building a dynamic building simulation was performed. Usage ratios (residential / trade and business), insulation and technical building equipment standards were given by the quality manual [3]. Two temperature reference years for Bamberg were simulated in an hourly resolution (Climate data of 2015 and 2045 of the German Meteorological Service). To assess the uncertainty of the development process a parameter study was conducted; possible sensitivities and risks have been quantified.

The electrical load profiles were generated based on the development plan [3]. The resulting time series, which differ by type of usage, were scaled and validated based on measurement data (types of usage: households, trade and business).

According to current plans, 2000 parking spaces will be built on site and operated by the municipal utilities. This demands a scenario for sizing and operation of the corresponding electrical charging infrastructure, which supplies private cars as well car-sharing vehicles.

The time series of heating, cooling and electricity demands form the base for the estimation of sector coupling potentials as well as the sizing and operation of the different systems (see 3.6).

3.2 Estimation and analysis of non-technical demands

Preferences and needs of potential inhabitants of the quarter were analysed by a team of psychologists from the Otto-Friedrich-University of Bamberg. An online survey was conducted on issues of sustainability with citizens from cities that resemble Bamberg with respect to size and infrastructure.

3.3 Examination of potential sources

PV-Systems

The quality manual demands the installation of PV systems on every new building [3]. To estimate the PV potentials on site, a yearly simulation of two reference years in hourly resolution was performed (Climate data of 2015 and 2045 of the German Meteorological Service). Two scenarios with different installation directions are simulated (east-west and south). The modules are simulated as poly crystal modules with 305 W peak power and an efficiency of 18.6%

Heating and cooling sources

In the first step possible sources for heating and cooling supply were identified. These were analysed and benchmarked by their potential, sustainability (rate of renewable energy, definition see [2]), costs of utilization, benefit for the energy system and location (On site energy generation is preferred.). **Figure 4** shows the priority of the conducted sources and divides them into three priority levels. The objective is to cover more than 50% of the energy demand by sources of stage 1.

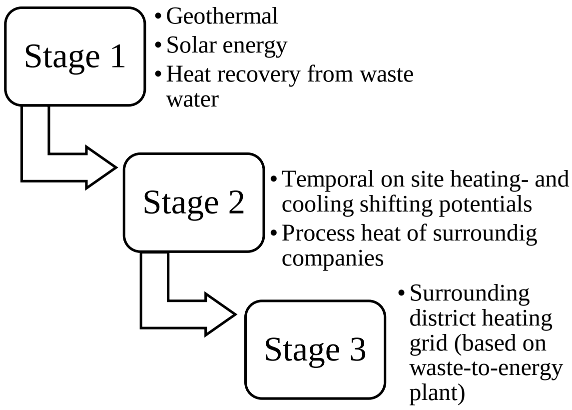

Figure 4: Energy sources and the priority of their usage

3.4 Examination of thermal storage potentials

The examination of storage potentials is divided in three steps. First existing storages on and besides the area were analysed. Second the potentials of the building mass and the decentral building thermal storage systems were analysed. In the last step central storage potentials were identified. The storage types investigated are surface collectors and probe fields, as well as an existing ice storage tank for a part of the seasonal shifts (Volume =444 m³, Maximum heating power = 135 kW, Maximum cooling power = 150 kW) and a central buffer storage for daily shifts.

Due to spatial conditions of the area (urban district) an optimal combination of all of these techniques have to be chosen, to maximise the rate of usage of renewable energy.

3.5 Design of district heating grid

To include low exergetic energy sources and to lower the distribution losses of heating systems, a low-temperature district heating system [9] will be built up. The integration of the existing building stock with its higher temperature requirements was addressed by the development of a cascading temperature system. This multi-zone network was first divided into supply areas with constant temperature levels. In the second step, possible routes for the high and low temperature, as well as the cascaded systems were planned.

3.6 Investigation of sector coupling potentials

One of the key objectives is to use the energy produced by the PV systems to maximise the electric self-consumption and the use of residual energy for heat generation. For that purpose plants like decentral and central heat pumps, a combined heat and power generation (CHP) units and power to gas units have to be sized, their operations have to be scheduled and the resulting energy flows have to be quantified.

To assess the optimal size of each system and to model the grid interaction the Fraunhofer tool "OptIn" was used, which is based on a mixed integer linear program (MILP) that combines all relevant cash flows and techno-economic constraints for the thermal and electric system based on time series of heating and electricity demands. The uncertainty of the investment decisions were assessed through a sensitivity analysis. **Figure 5** shows a simplified scheme of the optimization procedure, for further information see [10], [11].

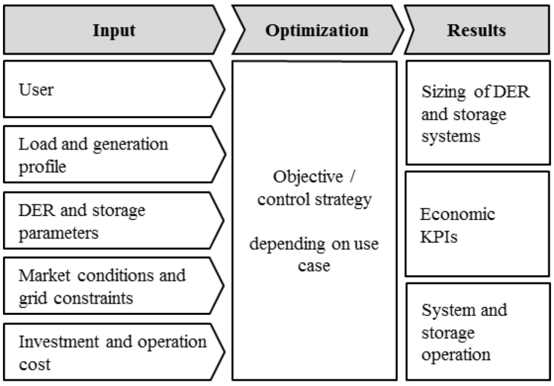

Figure 5: Simplified framework of the optimization procedure

4 Selected Results

Due to the size of the study, only selected results are presented and discussed below.

4.1 Power-, heating and cooling demands

For the estimation of the heating and cooling demands different scenarios with various insulations standards were analysed (see **Table 1**).

Efficiency Levels	New building (mixed usage)	New building (residential)	Building stock	Building stock (extended)
Upper	EnEV16	EnEV16	Modernized	EnEV16
Intermediate	EnEV16	KfW55	Modernized	EnEV16
Lower	KfW55	KfW55	Modernized	KfW55

Table 1: Simulated building efficiency levels (for a definition see of EnEV16, KfW55 see [12])

A distinction was made between usage (residential and business/trade), as well as building age (new buildings and building stock, here modernization plus extension). The scenarios are based on the requirements of the quality manual [3].

Buildings of intermediate efficiency show a peak heating demand of 7.8 MW, a peak cooling demand (residential only) of 3.3 MW and a peak electricity demand of 3.4 MW. Figure 6 shows the durations curves for the demands. The effects of electrical car charging are not yet included in the calculations.

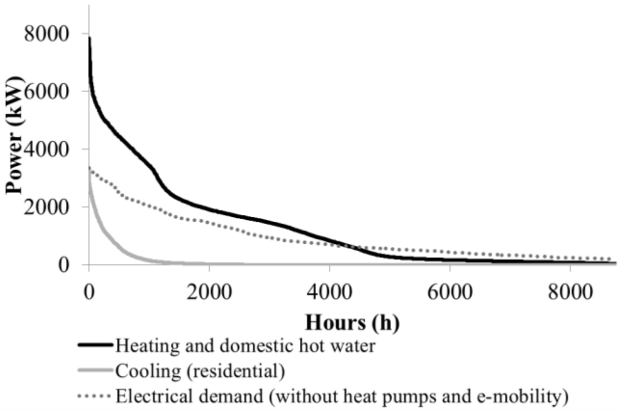

Figure 6: Annual load duration curve of aggregated heating, cooling and electricity demands

4.2 Energy sources & storages

The analysis of heat source potentials showed various potential sources: Two sources of industrial process heat, heat recovery potentials of sewage water. Environmental heat potentials can be tapped by lowering the temperature level of a central water supply pipe next to the area or with geothermal probes and as horizontal collectors on site. In addition to these low exergetic sources, connection to the existing district heating grid is possible, which is supplied by a waste-to-energy plant.

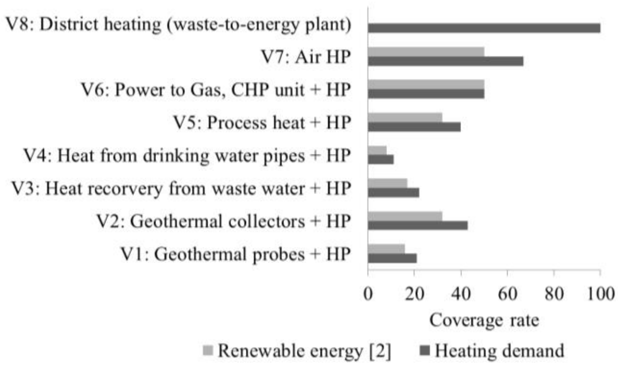

Figure 7: Coverage rates of different conventional and renewable energy supply variants

After benchmarking of these different concepts based on 3.3 and 3.4, a combination of supply variants 2, 3 and 7 were chosen for further investigations (see **Figure 7**).

To integrate the PV plants into the heating system additionally, a supply of decentral heat pumps and a central power-to-gas (PtG) plant will be examined (also see 4.5).

In the next step sub scenarios of the final supply variant will be analysed more in detail. Within sensitivity analysis the influence of different usage ratios (residential/business) will be assessed (see chapter 4.5).

4.3 Design of heating and cooling grids

An in temperature level cascaded district heating grid is planned, which will supplies both, existing buildings with higher and new buildings with lower temperature levels (see **Figure 4**). A central line connects the outlying district heating grid with the central energy hub. In the IT area (Zone 1) additionally a cooling grid will be built.

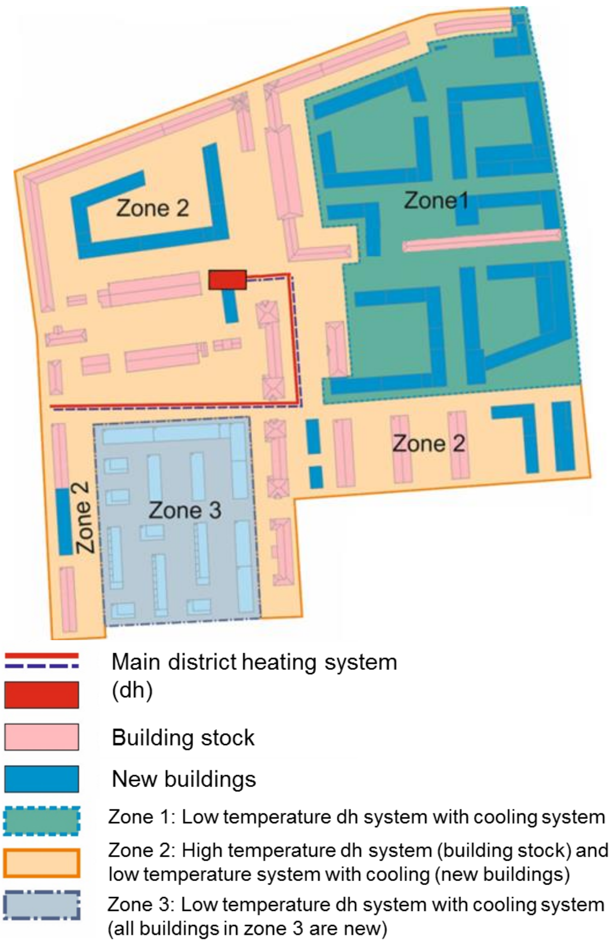

Figure 4 Concept of the heating- and cooling network

4.4 Analysis of non-technical demands

A total sample of N = 586 respondents with a mean age of 48.58 years (SD = 14.57) was analyzed. Thereof 445 of the respondents (75.9%) were willing to report their monthly gross income (Mean = 2,749.46 Euro; SD = 1,596.50). Most of the respondents were part of the working population (63.7%), followed by retired respondents (24.1%), other respondents not in the working population (7.2%) and respondents in academic or vocational training (5.1%).

79.7% of respondents have at least one car in their household of which 51.7% use it daily. Attitudes and needs were assessed on a 5-point scale ranging from 1 to 5 (strong disagreement to strong agreement). Overall respondents showed a preference for sustainability (M = 3.20, SD = 1.08). With respect to e-mobility attitudes diverge, however: While 20.0 % reported strong interest in using an electric motor vehicle in the future 25.8% were not at all interested. Furthermore, 11.3 % evaluated car-sharing opportunities in their immediate vicinity as attractive, while 40.8% did not consider them attractive. Interest in electric mobility and car-sharing was related to age with younger participants being somewhat more interested. Overall the data suggests that verbal overall acceptance of sustainability does not necessarily translate into specific intentions to use mobility that is sustainable. For the project's success it will be important to provide information to future inhabitants about sustainable options and their advantages as well as motivating and nudging them to use such options.

4.5 Sector coupling potentials

In addition to the usage of the PV generation for electric self-consumption, it should be used for heat generation with heat pumps (supply variants 2, 3) and gas generation within a power to gas process (supply variant 6). Here the idea is to store the produced gas in natural gas distribution grid in summer and use it for heat and power generation within a CHP plant in winter. To proof the feasibility of this complex concept the interaction between buildings and grid infrastructure was qualified for different system configurations with the objective of evaluating the PV generated energy that is usable for heat generation within heat pumps and the PtG process.

Two main plant configurations were distinguished, a decentralized where PV-systems, heat pumps and battery storage systems (BSS) are placed in every building and a centralized one, with a single heat pump and battery storage. The installation of battery storages was proofed to generate additional daily flexibility. For the central concept grid charges and taxes that have to be paid when using the public grid are neglected (in decentral concept they were considered). The key assumptions for the investigation were:

- Rate of return 4%
- Planning horizon 25 years
- Investment costs PV: 900 €/kWp (25a lifetime)
- Investment costs BSS: 400 €/kWh; 200 €/kW (20a lifetime)
- Electricity price 30 ct/kWh (reduced grid charges due to heat generation)
- Feed in rate of PV 4 ct/kWh
- Demands regarding chapter 4.1

The key findings of the first part of the investigation regarding the usage of PV generated energy can be summed up as follows:

- The existing PV potential is fully utilized for PV-systems in decentral and central variant.
- Depending on the orientation of the PV-system, self-consumption rates of 85-95 % are achieved. (Due to high electricity demands in business sector)
- Battery storage tanks and heat pumps contribute only minimally to increase self-consumption.
- The use of battery storages is not recommended.

By prioritizing the use of PV energy for heating over standard electric demand, PV-WP systems are able to cover 16% of heat demand in winter, 70% in transition period and 100% in summer, as shown in **Figure 9**.

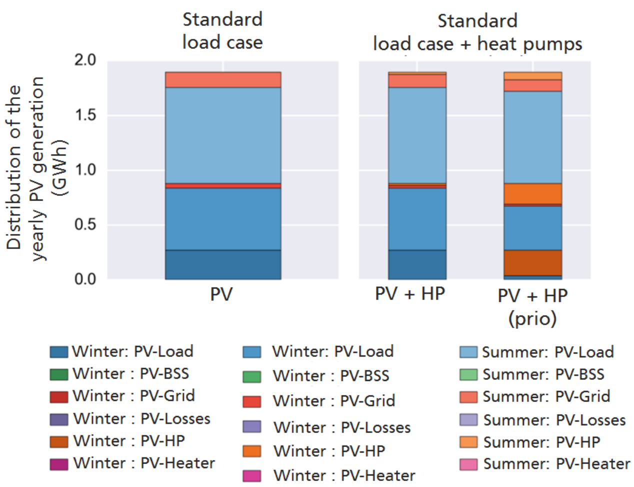

Figure 9: Usage of the PV generation during the year

The investigations have shown that the PV generation is mostly used for electricity self-consumption and heat generation with decentral or central heat pumps. The rate of usage is even higher, when the coupling (PV-HP) will be prioritized (supply variants 2 and 3 plus PV-systems). As a result the residual PV generation that could be used for the PtG process is small (see **Figure 9**) which influences the sustainability and the economic efficiency of supply variant 6. In the next step a detailed analysis will be carried out to clarify if the PtG process is a suitable solution in this context.

5 Next steps

In the next step the feasibility of the supply variant 7 will be analyzed, a scenario for the e-mobility will be developed and integrated into the concept. Finally a comprehensive overall concept for the implementation phase is developed.

The knowledge gained with the online survey helps within the investor selection process to formulate the needs of the future inhabitants and to develop an energy management concept which considers various psychological mechanisms and behavioural concepts of future inhabitants (e.g. design of feedback, nudging, framing effects, gamification, etc.).

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