Energy concept for Kreuzberg in the Ahr valley (SolAhrtal)

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***Abstract*—The proposed energy concept for Kreuzberg aims to significantly reduce greenhouse gas emissions, increase energy independence, ensure long-term price stability and promote a sustainable future through the implementation of a local heating network powered by a 3 MW heat pump system using energy from the river Ahr. This system, which uses a river water heat exchanger and a supply temperature of 40°C to maximize efficiency, will connect 141 of the 210 houses of Kreuzberg. The concept considers existing investments in a unique way by allowing homes with higher temperature requirements to supplement the supplied heat network output with their existing boilers, thus addressing the financial constraints following the flood disaster. With federal subsidies and an energy cooperative operating model, the project outlines an economically viable plan at €0.062/kWh as well as an €100/Month basic price and a one-time connection fee of €5,000 per house. In addition, by harnessing Kreuzberg's rooftop PV potential of 2,241 kWp, energy self-sufficiency could be achieved, generating approximately 2,100 MWh of electricity annually. This comprehensive approach, backed by extensive research and calculations, presents a viable and competitive solution for Kreuzberg's sustainable energy and economic regeneration, and demonstrates a forward-looking model for community-led energy transitions.**

Keywords—energy concept, local heating network, heat pump, PV-rooftop systems, river water heat exchanger, energy independence

I. Introduction & Motivation

The energy initiative is being executed in collaboration with the local municipality of Kreuzberg in Rheinland-Pfalz situated within the Ahrweiler district. Throughout the duration of this endeavor, the primary liaison has been the Mayor of Kreuzberg, Mrs. Anke Hupperich. Kreuzberg suffered substantial impacts during the Ahr Valley flood in July 2021, where, in addition to the flooding from the Ahr River, the water level of the considerably smaller Sahrbach also experienced a significant rise. Specifically, water levels peaked at 8 meters for the Ahr River (normal level 0.5 meters) and 6 meters for the Sahrbach (normal level 0.3 meters) [1]. Approximately 200 structures incurred severe damage as a consequence of these events, resulting in the destruction of energy infrastructure and heating systems. Beyond the imperative of restoring infrastructure, another driving force behind this initiative is the transition towards renewable energy sources, given the demonstrable correlation between flooding events and the anthropogenic greenhouse effect.

Furthermore, municipalities are obliged to submit a municipal heat planning by mid-2028 at the latest, and this energy concept makes an important contribution to this.

II. Kreuzberg

Kreuzberg is part of Altenahr in the district of Ahrweiler in northern Rheinland-Pfalz. Embedded in the Ahr valley, Kreuzberg borders the part of Pützfeld to the south and Altenburg to the east. Numerous elevations characterize the landscape, including the Lingenberg with a height of 243 m and the Pützberg with 375 m. The Ahr flows through the village and is fed by the tributaries Sahrbach and Vischelbach [1].

During the flood disaster in the Ahr valley in 2021, 73% of the heating systems in Kreuzberg were destroyed and 12% suffered partial damage [2]. Due to the emergency, many destroyed heating systems were quickly replaced by new fossil-fueled thermal systems and the switch to climate-neutral heat supply was limited. In addition to replacing the heating systems, large parts of the building structures and infrastructure also had to be rebuilt [3]. This required considerable financial resources and presented many owners with financial difficulties. Although the "Aufbauhilfe 2021" reconstruction fund was set up with 30 billion for the flood damage, only 2.35 billion of this has been called up (as of 26 May 2023) [4]. The initial situation in the Ahr Valley therefore appears to be a major challenge for the energy transition, as the financial resources are lacking and an almost complete transformation of the current structures would be necessary [2].

III. Methodological Approach

The methodological approach for the development of the energy and implementation concept in Kreuzberg includes several aspects. A questionnaire survey, digital mapping services and online resources are used to analyze the current situation. The data obtained is always checked for plausibility with data from guidelines such as the German Energy Agency (DENA) or simulation programs such as nPro Simulation. Online data such as the RLP solar cadaster or information from LANIS are also used in the analysis of renewable energy potential, and the Python framework PandaPower is used for the calculation of the electricity grid. Power system modelling is carried out using PyPSA (Python Power System Analysis) and the powerful Gurobi solver to solve the optimization problem. The nPro software is used to design the local heating system with all its components and parameters. All calculations, simulations and online data are always verified with data from the scientific literature.

IV. Inventory Analysis

The survey for the inventory analysis for Kreuzberg provides data to assess the current situation. Of the 28 respondents, 54% already use renewable energy sources such as environmental heat, pellets and wood. However, based on average data and information on the installation of heating systems after the flood disaster, a high proportion of fossil fuel heating systems can be expected. The average heating energy demand in Kreuzberg is about 21 MWh per household. The average electricity demand is 4.5 MWh per household. There is already 82 kWp of PV capacity installed in Kreuzberg [5]. Over 90% of Kreuzberg residents own a car with an internal combustion engine. The proportion of e-mobility is very low. On the other hand, the survey results show a high level of support for solar energy. Kreuzberg currently has an average electricity demand of 1.25 MW [6]. The average annual heat consumption is 4,254 MWh [7]. Local public transport is characterized by bus connections. Although Kreuzberg is connected to the railway network of the Lower Ahr Valley Railway (Remagen - Ahrbrück), large parts of this infrastructure have been destroyed since the flood. Individual transport is therefore still the main form of mobility in Kreuzberg.

V. Potential Analysis for renewable Energies

The potential analysis determines the usable possibilities and capacities for renewable energy sources such as photovoltaics, wind power, bioenergy, and hydropower.

A. Photovoltaics

With the help of the RLP Solar Cadaster, the PV potential in Kreuzberg is estimated to have a maximum capacity of almost 4 MW on rooftops [8]. Considering north-facing orientations and possible roof coverings, this results in a realistic potential of 2,241 kWp with an annual electricity production of 2,102 MWh. Greenfield PV is difficult to find in Kreuzberg due to the risk of flooding in the Ahr floodplain and the steep wooded slopes on the outskirts of the village.

Fig. 1. Central Kreuzberg from the air after the flood with the house-specific PV potential [8]

B. Windenergy

The potential for wind energy is non-existent due to the lack of wind priority areas and the numerous nature, bird, and landscape conservation areas in Kreuzberg [9] [10]. In addition, the municipal area of Kreuzberg is very small and, considering the topology and minimum distances from residential areas, does not offer any opportunities for wind energy [10] [9]. At best, wind energy could be developed in cooperation with neighboring municipalities and on their land.

C. Bioenergy

The potential for bioenergy is also analyzed. There is no agricultural land within the boundaries of Kreuzberg that produces biomass that could be used for energy. The amount of forestry waste generated in Kreuzberg is also estimated to be low. Organic waste in Kreuzberg is collected by the regional waste management companies and the quantities are too small for local use in a biogas plant [11]. A CHP plant fueled by imported pellets would be an option, but this is not being pursued due to environmental concerns.

D. Hydropower

The use of hydropower would be technically possible in the Ahr. With an average flow of around 6.86 cubic meters per second, electricity generation would be possible [12]. According to our own calculations, an exemplary run-of-river power plant for the Ahr would have a capacity of 130 kW and an annual yield of 750 MWh, using 40% of the Ahr's mass flow [13]. This could supply almost the whole of Kreuzberg. Due to strict water and environmental protection regulations, it is very unlikely that a hydroelectric power plant will be built in Kreuzberg in the near future [14].

E. Mobility

Kreuzberg is moderately integrated into the public transport network (ÖPNV) of the Rhein-Mosel Transport Association (VRM).. There is an hourly rail replacement service (SEV) to Ahrbrück and Bad Neuenahr-Ahrweiler, which is supplemented by direct bus connections to Adenau [15]. Rheinbach can also be reached via line 840. The railway station in Kreuzberg is part of the Lower Ahr Valley Railway, but is no longer accessible after the flood disaster due to extensive damage to the railway bridges.

VI. Electrical Grid Calculation

The calculation of the power grid in Kreuzberg is based on the official power grid plans of the responsible grid operator Westnetz GmbH (as of 4 July 2023) [16]. A section of the network map is shown in Figure 1.

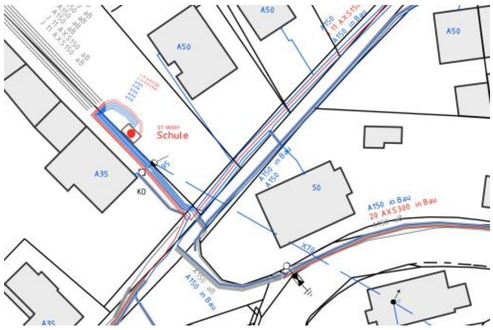

Fig. 2. Section of the Kreuzberg power grid map [16]

The grid calculations are carried out using the Python framework PandaPower, which enables comprehensive and precise simulation. Kreuzberg's electricity grid is implemented manually in the Python code according to the grid plans. Kreuzberg's electricity grid can be characterized by overhead lines with small cross-sections (x70, 70 mm^2) in the town center and underground cables with larger cross-sections (NAYY 4x150, 150 mm^2) in the outlying areas and new development areas. In Kreuzberg, four transformers with a capacity of 1210 kVA connect the local low-voltage grid (0.4 kV) with the regional medium-voltage grid (11.5 kV) [16].

The initial step consists of calculating the current state of the grid using the current power and consumption figures for Kreuzberg. The critical limit values for the utilization of the four transformers (up to 24.1 % utilization) are not exceeded. In addition, the voltage deviation ($\Delta U > 3$ %) and the maximum line current ($I > 270$ A) are not exceeded. This means that the current grid is fully functional.

In the first scenario, the grid is loaded with the maximum PV power of 3.95 MW, with a hypothetical consumption of 0 kW. All transformers are loaded to over 300%. In addition, 192 nodes (house connections) experience high voltage overshoots of up to 25% and 48 lines experience maximum current overshoots of up to 1000 amperes. In the following simulations, the PV power is reduced until no limits are exceeded. This is the case for an installed PV power of 257 kWp. A much higher output could be achieved by meshing certain grid lines and reinforcing the overhead lines in the city center. A controllable local grid transformer (RONT) could also increase the installable PV power to almost 800 kWp. Direct connection of hypothetical greenfield systems to the transformers could also enable an installable output of 1210 kWp.

According to the power grid plan, the capacity of the power grid is not sufficient to install 2,241 kWp of PV power. Since outdated power network plans were available for this study and the power networks have been modernized in the meantime and this new status could not be taken into account in our simulation, no statement can be made about the current capacity in the network.

VII. Energy System Modelling

The energy system modelling aims to determine sizes for possible components such as PV systems, heat pumps and storage for Kreuzberg with different degrees of self-sufficiency and the most favourable price. This should enable an overview and categorisation of the energy concept. Modelling is carried out using the Python framework PyPSA and the system is optimised using the Gurobi solver.

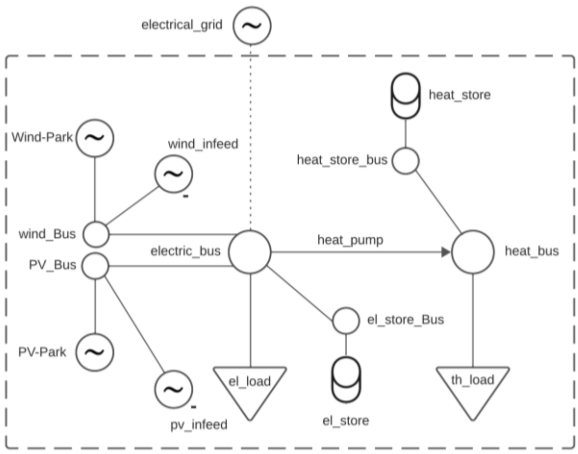

Fig. 3. PyPSA Energy System Modelling Kreuzberg

The system is implemented in Python code as shown in Figure 3. It consists of a PV park, a wind park, a power storage, a heat storage and a central heat pump. The necessary time series data such as wind speeds (from DWD as TRY), PV generation series (from PVGIS as TRY), H0 standard load profiles (from BDEW) and the heat standard load profile according to VDI 4655 are used [17] [18] [19] [20]. Simplifications and assumptions are made for the calculation. Different scenarios with different levels of self-sufficiency and system components are modelled and optimized.

The results show that full self-sufficiency requires significantly higher system outputs (PV: 5.1 MW, wind: 2.7 MW) and storage capacities (electricity: 1.8 MWh, heat 17.5 MWh) than 70 per cent self-sufficiency (PV: 0.6 MW, wind: 0,3 MW, electricity storage: 0 MWh, heat storage 3,2 MWh). Furthermore, a combination of wind and PV systems is the best way to supply Kreuzberg. Without wind energy, 22,6 MW of PV and 7 MWh of storage are required to provide 100% self-sufficiency for Kreuzberg. In the 70% scenario without wind, only 1,7 MW of PV capacity and 0 MWh of electricity storage are required. With the identified PV potential of up to 4 MW, it is not possible for Kreuzberg to be 100% self-sufficient.

VIII. Best-Practice Expert Interview

On 18.12.2023, an interview was conducted with the volunteer "construction coordinator" Rolf Schmitt, who made a major contribution to the realization of the local heating concept in Marienthal. For his special commitment after the flood of the river Ahr in 2021, he was awarded the second highest award of the state, the state medal of merit [21]. The interview with Mr. Schmitt is intended to make valuable experience and knowledge from Marienthal available for implementation in Kreuzberg.

In Marienthal, a local heating system fed by a pellet boiler with 33 house connections was set up by the citizens' energy cooperative EEGON. The pellet system is supported by a small ground-mounted solar thermal system. PV support was not possible in Marienthal due to the high level of shading from the surrounding hills in the winter months, which makes the use of heat pumps difficult. The pellet boiler in Marienthal can also be converted to other forms of energy, such as hydrogen, in the future [22].

The billing model in Marienthal includes a basic fee of €90 per month for the use of the local heating network, with heat consumption charged at 8 ct/kWh. The participating houses had to contribute to the investment volume. Single-family houses had to pay €15,000 and larger buildings €20,000. Thanks to subsidies and donations, the actual cost for households was between €3,000 and €4,500. Synergy effects were also achieved as water, electricity and fiber optic cables were laid at the same time.

The costs incurred by Marienthal are currently unaffordable. This is reflected in the neighboring communities, which are struggling with significant price increases and supply bottlenecks for their local heating networks. EEGON is responsible for installation and operation. A mini job has been created for the maintenance of the heating center. There is also a framework maintenance agreement with the manufacturer of the pellet system. In Marienthal, EEGON has taken over the financing, while the citizens must make their own contributions. It is important to note that building such a local heating network requires a considerable up-front investment, which should not be underestimated. Although subsidies will eventually be paid, equity or a bank loan will be needed to bridge the gap. Another challenge is the uncertainty about the number of connections, i.e. how many households will decide to connect to the local heating network. This goes hand in hand with the core problem of cost estimation. Homeowner motivation is also a critical issue. In Marienthal, the motivation to use a sustainable system was high due to the loss of heating systems after the flood. In places like Kreuzberg, where many have already installed their own new fossil fuel heating system, the motivation to connect to the grid is virtually non-existent. To do so would undo the investment they have already made. Many communities face this problem when implementing community energy schemes [22].

In Kreuzberg, the energy cooperative EEGON was already active, but decided not to implement a local heating network in Kreuzberg. The main reasons for this were the size of the village, the distances between the houses to be connected and the steep gradient in some cases. There was also no guarantee that the boiler house would be built in the required location in the village. EEGON's rejection of Kreuzberg casts a pessimistic light on the concept.

IX. Energy Concept Kreuzberg

In the context of developing sustainable energy supply systems, the energy concept for Kreuzberg presents a model example aimed at utilizing renewable energy sources to achieve climate neutrality in local building infrastructure heating. This concept aims to provide an environmentally friendly and efficient energy supply while taking into account the special geographical and social conditions of Kreuzberg.

The heart of the concept is a district heating network powered by an innovative heat pump. This pump efficiently harnesses environmental heat from the Ahr river flowing through Kreuzberg, thus serving as a climate-neutral primary energy source. The system is designed to provide a supply temperature of 40°C, facilitating direct integration into surface heating systems such as underfloor heating.

For buildings that lack such heating systems or require higher supply temperatures due to their structural condition, the concept offers an adaptable solution. These buildings can increase the base temperature using their existing heating systems (gas, pellets, oil, or electricity) to meet their specific heating needs.

A concept for heating the drinking water via the district heating network is also being implemented. This approach takes hygiene requirements into account by temporarily heating the water to 60°C to ensure protection against legionella. Decentralised instantaneous water heaters that can be operated with electricity from photovoltaic systems can be used to heat the drinking water, especially in the transitional and summer months.

This approach makes it possible to take into account different building standards within the community and ensures that the investments made in post-flood reconstruction are taken into account without excluding future-proof investments. As a result, only 141 houses out of a total of 210 houses will be connected to the local heating network. This results in a required network length of just under 2500 metres [25].

The concept utilizes a heat pump that taps into the Ahr river as a heat source through a river water heat exchanger. A crane system can position the heat exchanger just below the water surface of the Ahr. It is connected to the heat pump via flexible pipes which enables easy maintenance.

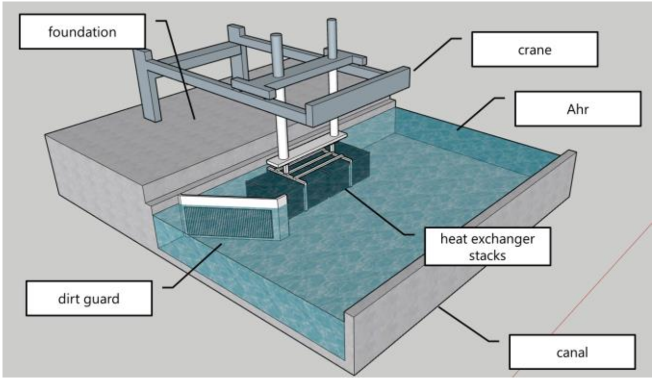

Fig. 4. CAD drawing of the heat exchanger and the crane system.

The efficiency of this system depends on the temperature levels, with a higher Coefficient of Performance (COP) achieved at lower temperature differentials between the source and usage temperatures. For an accurate efficiency assessment, the annual performance factor (APF) is used, which considers the heat produced in relation to the electrical energy consumed over a year. Since the annual performance factor is a parameter that is primarily measured under real conditions and includes energy quantities, such as those for pumps for heat transport through the local heating network, at the system level, this investigation approaches using the Seasonal Coefficient of Performance (SCOP). The SCOP is a weighted measure of the Coefficient of Performance (COP) over the course of a year, based on the required energy quantity.

The large heat pump will require a thermal output of around 3 MW to supply Kreuzberg. As individual systems in this output class are custom-built, this concept proposes a split between 3 commercially available heat pumps with 1 MW each. The VITOCAL 300-G PRO type from Viessmann with 1055 kW can be used here [24]. These systems can be connected in parallel to generate the required heating output together. This has the advantage of redundancy and reliability of the overall system. In addition, efficiency can be increased by avoiding partial load operation by switching off one of the heat pumps. Furthermore, the system is also cheaper as it is a series production. The natural refrigerant R600a (isobutane) is used for the design of the heat pump in accordance with the EU F-Gas Regulation. The following parameters are determined at the operating point with the largest temperature difference between the evaporator and condenser:

TABLE I. THERMODYNAMIC CALCULATION HEAT PUMP [23]

Paramteres	*Temperature [°C] / Pressure [bar]*	*Parameters*	*Temperature [K] / η [%]*
Local heating network	37 - 40 °C	Temperature spread for heat trasnsfer	6 K
Condensation of refrigerant	40 °C / 5,31 bar	Subcooling	10 K
Evaporazion of refrigerant	- 3 °C / 1,41 bar	Compressor efficiency	75 %
Ahr water temperature	min 3 °C	COP (SCOP)	5.18 (6.02)

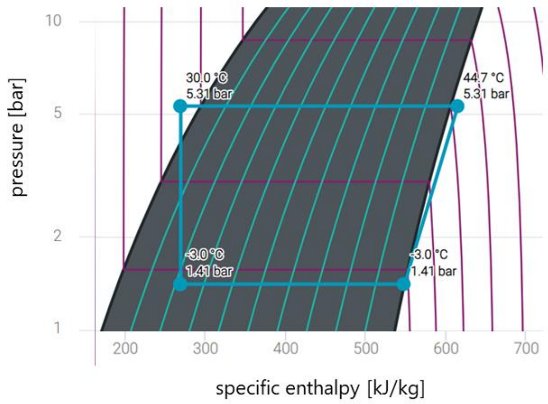

Fig. 5. Thermodynamic cycle of the heat pump in the p-h diagram.

With an extraction capacity of 3 MW and a flow rate of 6 cubic meters per second, the Ahr is only cooled by around 0.12 °C. This ensures that the extraction does not harm the ecosystem.

Another part of the energy concept are the PV systems on the roofs in Kreuzberg. However, these are private investments and are not financed by the community. The aim is to maximize the utilization of the identified usable PV potential of 2,241 kW distributed across the 210 rooftops. This could generate 2,102 MWh of green electricity per year. This would cover Kreuzberg's electricity requirements of around 945 MWh and the heat pump requirements of 707 MWh in the annual balance. In order to fully use the self-produced electricity, long-term electricity storage would be necessary, which would unfortunately be beyond the budget at the moment. This means that Kreuzberg would be partially climate neutral as part of this energy concept, as the 69 houses without a local heating connection will continue to be partly heated with fossil fuels [25].

In addition, the integration of photovoltaic systems also promotes the transition to e-mobility and in the future, bidirectional charging opens new potential for local energy management.

To financially support and promote local population participation, a citizen energy cooperative model is proposed. This model allows residents to directly participate in the energy future of their community and benefit from the economic and ecological advantages of the project.

The energy concept for Kreuzberg represents a comprehensive approach to realizing sustainable, climate-neutral energy supply. By efficiently using local resources, involving the community, and considering ecological aspects, the project makes a significant contribution to environmental protection and the promotion of renewable energies.

X. TECHNICAL IMPLEMENTATION

There are several aspects to the technical implementation of the energy concept.

First of all, various specialist companies and professionals are required, such as civil engineering companies, heating specialists, engineering firms, civil and environmental surveyors and consultants. The project process can be divided into the following steps.

1) Planning Phase: A technical requirements analysis and feasibility study is carried out during the planning phase. In addition, the local heating network is designed and the location of the heating center is selected. Once the technical parameters have been determined, the permit procedure can begin. At the same time, all the necessary work and components can be put out to tender.

2) Installation Phase: During the installation phase, the local heating network is constructed and the heating centre with the heat pump and the river water heat exchanger is built. The private PV roof-mounted systems can also be constructed. At the same time, the house transfer stations required to connect to the local heating network can be installed. The private PV roof-mounted systems can also be assembled.

3) Operating Phase: The next step is to integrate and calibrate the entire system. Commissioning and ongoing operation can then take place. This includes monitoring and maintenance, as well as customer support and energy management.

Based on the assumptions made, the total implementation time would be between 2 and 5.5 years (Derived from DIN 69901).

XI. FINANCING & PROFITABILITY

The total investment costs of the heat supply for 141 connected households, including the large heat pump (€ 1,911 million, [26]), the flow heat exchanger with peripherals (€ 100,000) and the local heating network with house transfer stations (€ 1,518 million, [29) amount to around €3,529,640. These values were calculated using standard market costs in accordance with the technical key figures of the energy concept. The power supply from 2,241 kWp of PV power costs a total of around € 3,361,950 for the 210 houses in Kreuzberg [27]. These are static investment costs excluding subsidies, financing and operating costs.

The federal subsidy ZUG supports the preparation of municipal heat planning, with financially weak municipalities receiving 80 % of the costs [30]. In the case of an energy co-operative with municipal participation, it would be possible to submit an application in Kreuzberg and save costs. The BAFA subsidises the construction of new heating networks with renewable energies in several modules. Feasibility studies are subsidised by 50 % and the construction of a new network with a heat pump, local heating network and peripheral systems is subsidised by 40 % and energy cooperatives also receive funding. In addition, the BAFA also subsidises the operation of heating networks with renewable energies. If the house transfer stations are privately owned, they are subsidised by the BEG EM with 30 % [30].

For financing purposes, the investment costs are divided between communal and private costs after the subsidisation. The houses must make a one-off payment of € 5,000 for the house transfer station in order to be connected to the local heating network. These costs are not included in the financing of the rest of the system.

Taking into account the subsidies, a loan interest rate of 4 %/a, operating costs of 1 %/a, depreciation period according to AfA and the resulting annuity, the following capitalised annual costs result:

TABLE II. ECONOMIC CALCULATION HEATING NETWORK [25]

Component	*Investment after subsidy [€]*	*Annuity [%]*	*Operating costs (at 1 %) [€/a]*	*Capitalise cost [€/a]*
Heat pumpt	1,146,600	8.99	11,466	114,592
Heat exchanger	72,000	8.99	720	7,196
Local heating network	488,184	5.05	4,882	29,547
Total costs				**151,335 €/a**

Based on this calculation, the annual capitalised costs for the local heating network amount to around € 151,335 per year. These costs would have to be borne by the energy cooperative that builds and operates the local heating network.

TABLE III. OVERVIEW OF KEY DATA FOR THE HEAT CONCEPT

	Overall Heat demand	*Heat demand – Heating Network*	*Electricity demand heat pump*
MWh/a	5.967	4.170	706,69

Based on the capital-bound costs per year and the 141 connected subscribers, along with a profit margin of 10 %, the resulting base price is 1,811 euros per year. The heat energy price is determined by the electricity demand of the heat pump multiplied by the electricity procurement costs, divided by the heat demand and the profit margin. The energy cooperative can thus offer its subscribers an energy price of 0.062 €/kWh [25].

TABLE IV. OVERVIEW OF KEY DATA FOR THE PV CONCEPT

	PV installed capacity	*Municipal electricity demand*	*Internal consumption*	*Grid feed-in PV*
Unit	kWp	MWh/a	MWh/a	MWh/a
Value	2.241	2.030	630,6	1.471

The following assumptions are still crucial for determining the economic indicators of the energy concept:

- Feed-in tariff up to 10 kWp: 0.0811 €/kWh
- Electricity price for grid consumption: 0.33 €/kWh
- Volume discount for the procurement of all PV systems centrally: 20 % of investment$_{PV}$
- Investment costs for 2.241 kWp PV systems: 3.361.950 €.

This results in annual revenues of 119,331 €/a due to the direct feed-in of electricity from PV systems. Furthermore, due to self-consumption, grid electricity is avoided, resulting in savings of 208,098 euro per year. In total, this leads to revenues of 327,429 euro per year. Due to the varying installed PV capacities per building, it is not feasible to calculate an annual revenue per subscriber. Therefore, a specific value per kWp per year is computed. For the location of Kreuzberg, this value amounts to €146 per kWp per year. In contrast, the specific investment costs amount to €1,200 per kWp. It is noted that this value includes a discount of 20% on the investment costs. Subsequently, a specific payback period of 8.21 years is derived for all investors in PV systems in Kreuzberg.

XII. CORPORATE FORM

The energy concept for Kreuzberg is to be implemented through the establishment of an energy cooperative. Despite the challenges faced by the EEGON energy cooperative in the past, the optimism for a new project remains.

The decision to choose the operating concept of an energy cooperative has numerous advantages. On the one hand, it allows for direct participation and co-determination of the members in the project, which leads to greater acceptance and support among the local population. The cooperative structure also promotes local economic cycles and can contribute to the social and economic strengthening of the community by reinvesting profits in the project or in other sustainable projects. In addition, the cooperative form offers the possibility of obtaining subsidies and favourable financing conditions, which are crucial for the implementation and operation of renewable energy projects. In addition, a cooperative does not act for purely economic reasons, but for a common purpose. A cooperative is financed by the capital contributions of its members. Another incentive to become a member of the cooperative: The cooperative is allowed to sell the heat energy at cost price. Any surplus generate can be paid out to members at the end of the financial year. The cooperative gives citizens the opportunity to participate in energy production without major hurdles and at the same time generate benefits for themselves. Municipalities can thus involve their citizens in local energy transition and climate protection activities [30].

XIII. OPERATING CONCEPT

The local heating network should also be operated by the energy cooperative. It should take over the management and maintenance of the network, with maintenance contracts being signed with the manufacturers of the heat pumps and the river water heat exchanger. This has several advantages: Manufacturers often have in-depth knowledge of their own systems and can offer specific maintenance and repair services that include preventive measures and rapid fault diagnosis. Specialist contractors also often bring industryspecific experience and technical know-how that is crucial to maintaining the efficient operation of the local heating network. The system performance of heat pumps and heat exchangers can be monitored remotely by the manufacturer or maintenance company, and checked and repaired in the event of problems. Daily maintenance for electric heat pumps is limited compared to pellet CHP systems. The river water heat exchanger needs to be cleaned regularly.

Billing and customer management are other key tasks during operation. This includes the accurate recording of customer heat consumption, fair and transparent billing and customer service. As the customers are often members of the energy cooperative, it is in their own interest that the operation runs as smoothly as possible. For administrative tasks, responsible persons should be appointed and paid.

A heat pump-based heat supply is always at risk of failure in the event of a power cut. As the local heating network also serves as a buffer storage, it can be used to bridge short-term power cuts. In the event of longer power cuts, the existing fossil fuel heating systems could be used as a back-up. The use of several heat pumps in parallel reduces the risk of the whole system failing during operation by providing redundancy.

CONCLUSION

The energy concept developed for Kreuzberg shows a way to reduce greenhouse gas emissions, achieve energy independence, long-term price stability and a sustainable structure for the future. The energy concept is based on a local heating network fed by a 3 MW heat pump system. The heat pump uses the energy of the river Ahr with a river water heat exchanger. Combined with a supply temperature of 40°C for the local heating network, the heat pump achieves a very high level of efficiency. For economic reasons, the local heating network is to connect the compact centre of Kreuzberg, with a total of 141 of Kreuzberg's 210 houses being connected to the network, which is almost 2,500 metres long. Houses with panel heating systems will be able to use this temperature for their heating needs, while houses that require higher temperatures will be able to use their existing fossil fuel boilers to raise the temperature. This means that the investments made after the flood disaster will not be lost. This addresses a major problem in Kreuzberg, where there is a desire for a greener future, especially after the climate change-induced flood disaster, but where there is little financial resources available after the flood [1] . However, the economic case for the proposed energy concept shows an affordable option for the citizens of Kreuzberg. Federal subsidies, economies of scale and synergy effects for the components, and the highly efficient use of river heat allow costs of 0.062 €/kWh of thermal energy. In addition, there are one-off connection costs of € 5,000 per house. It is proposed to install, finance and operate the local heating system through the establishment of an energy cooperative. This will enable citizens to participate directly in the energy transition, create acceptance and stimulate the local economy. In addition to the sustainable heat supply, the electricity supply will be provided by private PV rooftop systems. In Kreuzberg, there is a usable PV potential of 2,241 kWp distributed over 210 roofs. Fully exploiting this potential would generate around 2,100 MWh of electricity, making Kreuzberg almost self-sufficient with the proposed energy concept. Other renewable energy sources are not feasible in Kreuzberg due to the current legal situation.

In conclusion, it can be stated that the energy concept that has been developed, with the help of numerous simulations, calculations, research, interviews and modelling, represents the best option for sustainable energy supply for Kreuzberg in the eyes of the authors. The costs of the heat supply are competitive and sustainable in the long term and the power supply with private PV systems is economically attractive. In this way, Kreuzberg can save considerable amounts of greenhouse gas emissions and create long-term sustainable structures.

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