FTI Initiative Energy Model Region

Publishable final report

Programme control:
Climate and Energy Fund

Programme management:
The Austrian Research Promotion Agency (FFG)

Final Report
created on
30/09/2023

Project title:
InduGrid

Project number: 868708

Call	II. Call FTI Initiative Energy Model Region
Project Starting Date	01/09/2018
Project Ending Date	28/02/2023
Total duration of project (in months)	42 Months
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InduGrid

Industrial Microgrids

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1 Table of content

2 Introduction

2.1 Initial situation at the beginning of InduGrid

The exchange of energy or the provision of energy contingents across company borders presents significant economic potential, but it is currently constrained by a range of technical, legal, and organizational barriers. However, the EU Winter Package [1] introduced a new legal framework designed to facilitate the formation and operation of energy communities. This framework simplified the exchange of renewable energy across company boundaries, likely encouraging companies to actively seek partners for energy exchange collaborations.

While these regulatory changes create new opportunities, they also raise important questions for companies looking to join or establish energy communities:

- Which companies are most suitable to form an energy community? Identifying the right partners is crucial to ensuring compatibility in terms of energy generation, consumption patterns, and operational goals.

- Who will coordinate the production, transmission, and storage of energy within the community? Effective coordination is essential for optimizing energy flows, ensuring reliability, and managing shared resources such as storage systems.

- What are the economic benefits of participating in such a community? Companies need to assess the potential financial advantages, such as cost savings through optimized energy use, shared infrastructure, and reduced dependency on external energy providers. This also includes the impact of regulatory incentives for renewable energy exchange and any long-term strategic gains, such as energy independence or sustainability goals.

These emerging questions highlight the need for careful planning, strategic partnerships, and clear governance structures to ensure the successful implementation of energy communities under the new legal framework. Companies must evaluate not only the technical feasibility of energy exchange but also the organizational and economic models that will enable sustainable and mutually beneficial collaboration.

2.2 Focal points of the project

The focus of the project consists of the following pillars:

- Creation of a platform for mapping energy consumption and generation in a spatial and temporal context with energy flow optimization (demand/supply), considering legal, technological, and economic factors to assess technology-based services and their underlying business models for economically viable decarbonization.

- Establishment of test beds for industrial energy communities to validate the platform, for practical testing and for the demonstration of energy exchange at several sites (Wels, Ennshafen, Hagenberg) with different focus areas (thermal exchange, electrical exchange, combined thermal electrical exchange).

- Development of new business cases for operators and new players and their validation in simulation using the developed energy exchange platform.

- Assessment of socio-economic impacts and public values, evaluation of awareness and involvement of companies/employees and user acceptance and evaluation of the flexibility of companies' internal operational structures.

2.3 Placement in the Program

The principal objectives of the program are:

Objective 1: *Development and model use of local energy and energy-related transport technologies for the large-scale field testing of intelligent system solutions in live operation. The model region should demonstrate that, by applying Austrian innovations, an up to 100 % renewable energy supply is achievable, makes economic sense, and offers ecological advantages.*

InduGrid brought an input by researching methods focused on inter-company energy exchange, the challenging task of finding appropriate partners, and the viably operation of renewable energy communities. The first task related with to this topic are the requirements and restrictions of the legal framework in Austria

The energy exchange between two or more companies could be - beside economic and technological questions- subject to legal obstacles. While the exchange of thermal energy beyond company borders could be carried out quite easily, the sharing of energy via the public electrical power grid and gas pipelines was highly restricted.
When the new law for developing of renewable energies (Erneuerbaren-Ausbau-Gesetz) came into force, new framework conditions were defined.

Objective 2: Strengthening and developing Austria as a lead market for innovative energy and energy-related transport technologies and services. The lead market assists Austrian businesses in positioning themselves as lead suppliers and acts as a visible point of reference in the international market.

InduGrid investigated the possibilities of optimal energy production and sharing between companies. A main task in InduGrid was the creation of a platform for mapping energy consumption and generation in a spatial and temporal context with energy flow optimization. Main points of that development have been:

> *Optimization criterions*: Standard approaches in numerical optimization consider the minimization of a linear combination of costs, which can be direct economic costs expressed in Euros, ecological costs for example as CO2 emissions, investment costs, tariffs, royalties, and many other cost factors. Already for a single entity, balancing those cost results in conflicting interests which must be resolved.
>
> *Advanced control strategies for sector coupling*: The simultaneous consideration of electricity and heat required to set up control strategies which must also cope with the transformation of energy into other forms. Control-oriented models for sector coupling have been developed and integrated in the optimization formulation.
>
> Automated optimization formulation: The innovative aspect of the current research proposal was to formulate the control problem in such a way that changes in boundary conditions and members are automatically translated into a new optimization formulation. In this way, the developed energy exchange map retains its validity past the project runtime. Furthermore, integration of new members and keeping the map up to date is a rather straightforward task which can be completed by a non-expert in control systems engineering or mathematical sciences.
>
> Complexity reduction: Once the optimization problem is formulated (time consuming and typically done for a specific problem), it must be solved to arrive at the specific strategies which have to be implemented at the participant level.

Objective 3: Involvement and active participation of users. The model region should demonstrate the use of energy technologies as close to actual operating conditions as possible. This requires the involvement of users-businesses, end users, local communities, etc.

For producers of larger amounts of energy the possibility to market their production or consumption profile in the balancing market represent a feasible marketing option. Either they use the technical prequalification themselves to gain accreditation as a supplier of control energy, or they join a pool. Based on the fluctuating profile of most renewables the possibilities are limited. On the other hand, the current support system itself limits the possibilities for fluctuating and non-fluctuating renewable Energy System producers.

“Gemeinschaftliche Erzeugungsanlage” – a common power plant whose produced electricity is used locally by at least two identities. The produced electricity is virtually accounted to the consumption of the participants and thereby saving them costs connected to electricity taken from the grid.

2.4 Methods used

To implement all project goals, different test fields were examined at three different locations in Upper Austria (Hagenberg, Ennshafen and Wels).
The following methods have been used within the project

- Collection of legal, economic and technical boundary conditions
- Data collection of already existing systems in operation
- Model building of energy systems
- Optimization of energy systems
- Test bed evaluation
- Creation of business models
- Socio-economic evaluation

2.5 Structure of the work

The primary contribution to the project goals is detailed in Chapter 3. Section 3.1 is dedicated to outlining the boundary conditions of thermal and electrical energy exchange in Austria. Section 3.2 focuses on the development of the energy exchange platform, while section 3.3 provides a comprehensive description of the test beds and their individual business cases. The final two subchapters are reserved for the analysis of socio-economic impacts and the dissemination activities

3 Content presentation

3.1 Boundary conditions for energy exchange and sector coupling

3.1.1 Technical conditions

At the start of the InduGrid – Industrial Microgrids project, a comprehensive analysis of the boundary constraints for energy exchange across (industrial) company borders was conducted. This analysis encompassed technical, economic, and legal aspects.

In this task, the initial step involved collecting and organizing the physical parameters of relevant forms of excess energy through desktop and secondary research. For each form of excess energy, the best available energy conversion technologies and their associated technical parameters were identified. The limitations of these technologies and their compatibility with various industrial applications were analyzed and translated into simplified mathematical models for energy conversion. To determine the appropriate conversion technology for each form of energy, key factors such as the transportation medium, energy quality, and energy quantity were considered. Table 1 provides a summary of the evaluated conversion technologies along with the corresponding input and output energy parameters.

Table 1: List of conversion technologies

	Input Energy		Output Energy		
Transformation Equipment	Medium	Quality	Medium	Quality	Transformation Efficiencies
el. Transformer	Electricity	0.4-35kV	Electricity	0.4-35kV	0.97-0.99
el. Boiler	Electricity	0.4-35kV	Hot water	30-99°C	0.99
el. Steam generater	Electricity	0.4-35kV	Steam	100-170°C	0.99
el. Superheater	Electricity	0.4-35kV	Dry Steam	100-170°C	0.99
Steam turbine	Steam	>300°C	Electricity	0.4-35kV	0.3-0.4
ORC turbine	Steam /Hot water	80-300°C	Electricity	0.4-35kV	0.2-0.36
Heat exchanger	Hot water	30-99°C	Hot water	30-99°C	0.99
Heat pump	warm water	10-50°C	Hot water	30-99°C	2 - 8

3.1.2 Economic conditions

In addition to technical boundary conditions, the next phase involved conducting desktop and secondary research on cost parameters and related expenses of energy conversion technologies, enabling energy exchange (refer to the conversion technologies listed in the previous table). A flexible, adaptable methodology for calculating energy conversion costs, incorporating both technical and economic

framework conditions, was developed and applied to the relevant energy conversion options for this project.
Key cost parameters considered include investment costs, fixed operating costs, and variable operating costs for each technology. By utilizing conversion efficiency, the matching hours between the excess energy source and potential energy sink, and economic variables such as depreciation period, interest rate, and the possible cost of excess or auxiliary energy, the tool developed for this project enables the calculation of comparable energy conversion costs, which is then applied in other parts of the project.

3.1.3 Legal conditions

During the course of the project, Austria's legal framework for energy sharing and exchange evolved with the implementation of the new Renewable Energy Expansion Act (EAG – Erneuerbaren Ausbau Gesetz). The relevant legislation governing the exchange of thermal and electrical energy was reviewed and compiled [2], [3], [4]. In addition to analyzing current laws, anticipated future conditions for the operation of energy communities was also assessed. The primary legal foundations for energy communities considered were:

- Art. 16 of The Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, refers to "Citizen energy communities".
- The Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast), where Art. 22 is dedicated to "Renewable Energy Communities"
- Some key aspects of both types of Energy Communities:
    - Main objectives: environmental and society benefits, not primarily for profit, local involvement
    - Participation: individuals, local administrations, small businesses
    - Governance: legal entities, control by members/share owners
    - access to energy markets, joint use of generated energy

In July 2021 the Erneuerbare-Ausbau-Gesetz-Paket was approved in Austria. The changes and clarifications that came along with this law (or more precisely: package of laws) were updated. It was be summarized that the changes in heat exchange were minor. The changes in the power market design were – as expected – tremendous, but not surprising about the directives. The use of local/regional tariff rebate for proximity, network levels 7 and 5 as a criterion for local/regional proximity and subsidies were clarified. Still, and in accordance with the directive, large companies were not allowed to participate in this type of energy communities, i.e. so-called renewable energy communities, making this solution uninteresting for the project partner companies. Citizen energy communities were regulated but did not offer significant monetary advantages. Still, direct lines were a potential solution for companies situated close to each other.

In coordination with the project partners, four scenarios / system configurations were developed and legally assessed for the electricity sector and three for the heating sector.

Various laws were checked for their applicability in the scenarios in question. For this purpose, the relevant provisions were searched for by means of legal, literature and judicature research, and their applicability was assessed. Where there is a need for interpretation, this was pointed out and an analysis was carried out using legal interpretation. In cases where this was not sufficient, the need for clarification was formulated.

The exchange of electricity between two companies could theoretically be imagined in various constellations. Both the supply of electricity via the public grid and the supply via a direct line are possible approaches, as was an electricity exchange within a closed distribution network (within the framework of a Citizens Energy Community) or in a Renewable Energy Community.

There was no specific legal framework for heat (pipes) [4], as was the case with the energy sources of electricity or gas. Several legal acts were therefore relevant for the proposed energy exchange systems. However, the scenario of feeding into an existing district heating network, which was to be classified as essential, was at that time being addressed.

Both the Energy Efficiency Directive 2018 and the Renewable Energy Directive 2018 considered the use of waste heat to be essential and important for decarbonization.
The incentive based on the share of waste heat and renewable energies in the district heating supply is expected to become effective. Further legal accompanying measures, e.g. a definition of (contractually adaptable) standard cases of cooperation between network operators and third-party providers could have a supporting effect

3.2 Energy exchange platform

3.2.1 Preparation for Optimization

The boundary conditions outlined in Chapter 3.1 were formalized to support their use in the subsequent optimization process. Various approaches to modeling the legal and technological aspects of energy communities were explored and evaluated. The Unified Modeling Language (UML) was selected as the most suitable method for this purpose. The UML model was then employed to structure the boundary conditions for a mathematical optimization task, aimed at coordinating efficient energy flows within the targeted industrial energy communities. Figure 1 illustrates a sample portion of the UML description

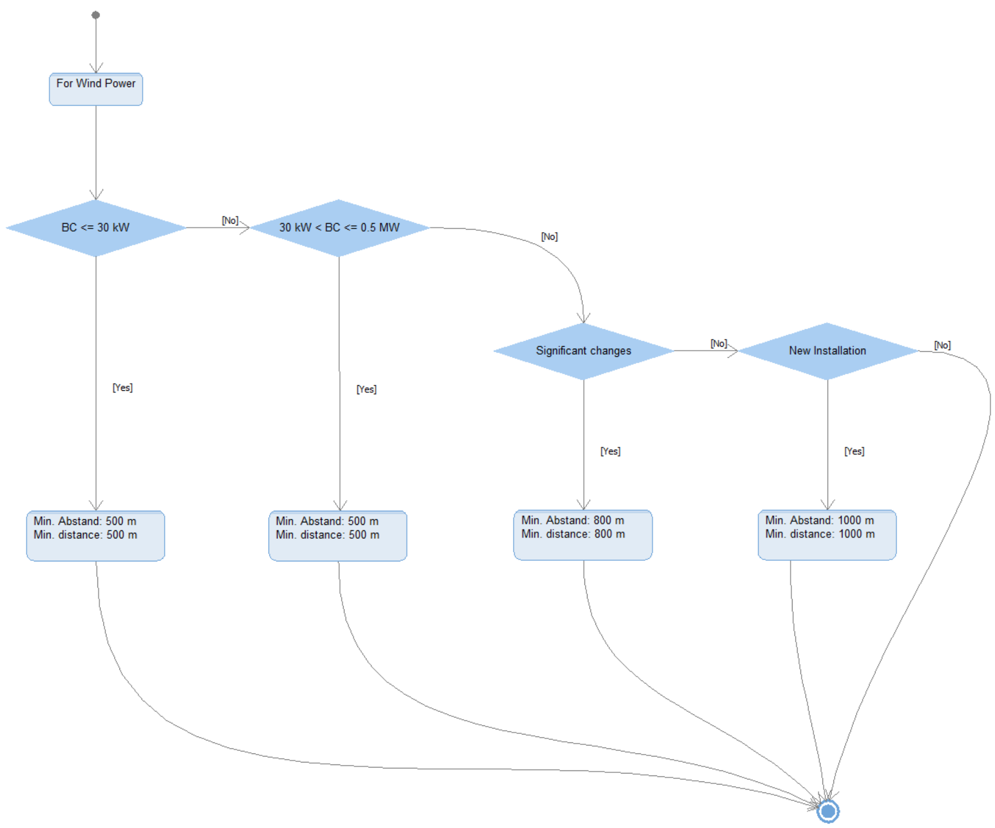

Figure 1: Example for the formulation of legal text in UML: minimum distances between a power plant and designated areas

In the second step, a comprehensive list of parameters was developed to accommodate user needs when utilizing the energy exchange platform. These parameters are organized into different levels, corresponding to entities such as legal persons, companies, buildings, and components. Some parameters function as user inputs or calculate key properties, while others facilitate critical linkages between the different levels. Covering both economic and technical aspects, these parameters form the foundation for the full realization of the InduGrid ecosystem, including its framework conditions, energy exchange platform development, and new business models. The technical parameters encompass aspects related to transport and conversion mechanisms, energy storage components, and simulation. A subset of these parameters, categorized at different levels, is illustrated in Figure 2.

Level n-1	Level n	Level n+1	Level n+2	Level n+3	Level n+4
Legal Person	Company	Building	Components	Sub-Components	Calculations
Parameter	Parameter	Parameter	Parameter	Parameter	Parameter
Overall Electricity Production	Aggregate Production of Electricity	Aggregate Production of Electricity	Aggregate PV Production	Total New PV Produce	New PV Array
Overall Electricity Consumption	Aggregate Consumption of Electricity	Aggregate Consumption of Electricity	Consumption	Total Existing PV Produce	Old PV array
Overall Renewable Penetration	Aggregate Production of Heat	Aggregate Production of Heat	Optimum Consumption Increase in present situation		
Overall Heat Consumption	Aggregate Production of Heat	Aggregate Production of Heat			
Overall Heat Production		Grid Connection Level	Storage Components		
Overall monetary benefit from Platfom	Production Profile of Electricity	Electricity Balance of B_i			
	Consumption Profile of Electricity	Heat Balance of B_i			
	Production Profile of Heat				
	Consumption Profile of Heat	LCOE Electricity			
		LCOE Heat			
	Total Current Electricity Expense	LCOE Custom			
	Total Current Earning for Electricity				
	Total Current Heat Expense				
	Total Current Earning for Heat				
	Types of Heat at level n				
	LCOE_Electricity				
	LCOE_Heat				
	LCOE_Custom				

Figure 2: Levels and parameters for boundary conditions

The traceability of requirements was a central necessity in the InduGrid project. Requirements may be derived from legal texts or may be technical or business-related in nature. Since these requirements often exist in an informal form, such as textual descriptions, automated verification is generally not possible. Therefore, a more precise articulation of the requirements is essential. A single sentence in a text document can often lead to multiple specific requirements, which typically have a higher level of detail.

For automated verification of requirements, it is also necessary to understand the relationship between them. For example (Figure 3), let us assume the above-mentioned sentence represents Requirement R1, which is refined into Requirements R100, R201, and R203. In this case, the relationship between the requirements could be expressed as follows: R1 → (R100 AND R201) OR R203. This means that the informal requirement R1 is fulfilled if the formal requirements R100 and R201, or alternatively R203, are fulfilled. The relationship between the requirements is represented in the mapping descriptors – in the diagram by a diamond shape.

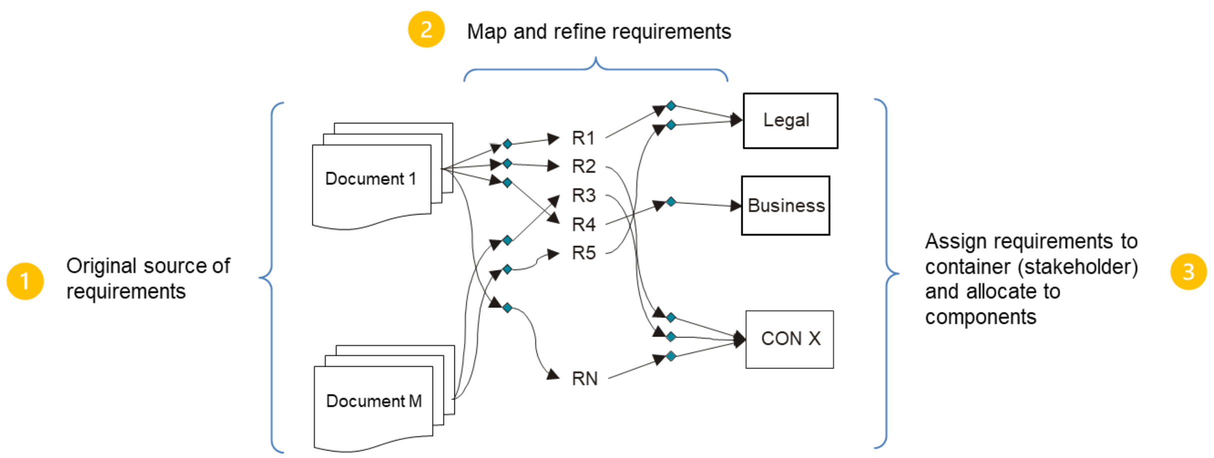

Figure 3: Traceability of requirements

If, for example, no companies can be found that meet the criteria for sector coupling – meaning R203 and R100 cannot be fulfilled – then the question arises as to how the original requirement was formulated. This could indicate that certain formulations in a legal text are too restrictive. For this reason, it is important that the origin of a requirement can be traced back to the original text document with references to page and line. This is known as backward traceability. Conversely, if one wishes to know the impact of certain text passages on a system, the relationships between the requirements can be traced through forward traceability.

The requirements are assigned to various containers, which in most cases represent the relevant stakeholders. This allows for quick identification of requirements that might potentially change if a stakeholder is modified.

3.2.2 Structure of the optimization process

At the core of the energy exchange platform lies a mathematical optimization tool, purpose-built to minimize the operational costs for companies participating in the energy exchange. This optimization tool serves as the foundation for coordinating energy flows and ensuring cost-effective energy management within the platform.

The software architecture supporting this tool was designed with flexibility and scalability in mind. It allows for the seamless import of company-specific data, such as energy consumption patterns and generation capacities, as well as detailed planning schemes. Moreover, the platform can integrate legal, economic, and technological boundary conditions, modeled using Unified Modeling Language (UML), as discussed in Chapter 3.2.1. This integration ensures that the optimization process adheres to all relevant regulatory frameworks and technical constraints.

The optimization tool itself was developed in MATLAB ©, which was selected for its robust computational capabilities and ability to handle complex algorithmic tasks efficiently. This tool acts as the core engine of the energy exchange software, enabling the analysis of consumption and generation data from multiple partners - ranging from 2 to N participants [5]. By analyzing this data, the tool can identify the optimal operational exchange behavior, determining the most efficient energy flows between participants based on real-time or forecasted data.

Key outputs from the optimization model include:

- Optimal Energy Flows: The model calculates the most cost-effective energy distribution for each participant, ensuring that excess energy is shared optimally within the community.
- Cost Analysis with and without Storage: The model provides a comparative analysis of operational costs, both with and without the inclusion of energy storage units, allowing participants to evaluate the benefits of incorporating storage systems.

- Net Purchase Costs: The tool calculates the costs associated with purchasing energy from external sources, factoring in market prices and grid access fees.

- Internal Energy Trade Costs: The optimization model determines the energy costs for transactions within the energy community, offering insights into how internal trading can reduce dependence on external energy providers and lower overall operational costs.

In essence, this optimization tool not only enables the efficient coordination of energy flows but also provides participants with valuable financial insights. By comparing different operational scenarios - such as the use of storage or reliance on external energy sources - the tool empowers companies to make informed decisions, maximizing their energy efficiency and minimizing costs within the industrial energy community.

Electrical energy community
The optimization model was structured into generalized plant models, encompassing electrical loads, photovoltaic (PV) systems, and storage units. Each model includes eight distinct energy flows (respectively stored amount of energy) that are optimized at every time step to ensure efficient energy management – see Figure 4).

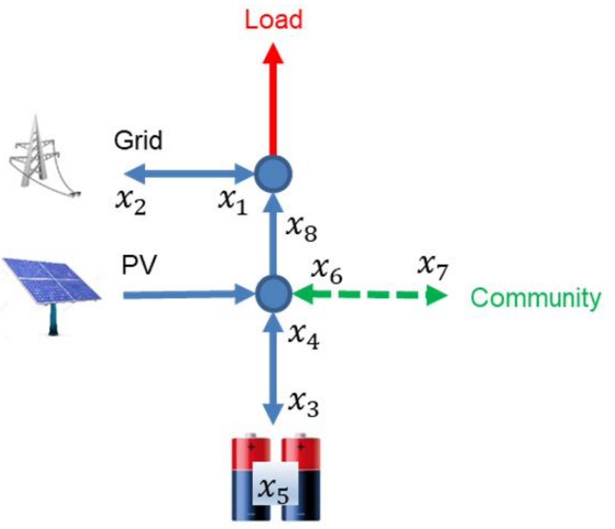

Figure 4: Structure of energy flow optimization of one single participant in an (electrical) energy community. States x_i consider power flow at every time instant.

The optimization software enables the interconnection of N participants within a (virtual) energy community, allowing them to produce, exchange, store, sell, or purchase renewable energy. The optimization task is formulated as a linear programming problem, incorporating both equality constraints (e.g., power balance, state-of-charge balance for storage systems) and inequality constraints (e.g., maximum and minimum power limits, storage capacity restrictions) at each time step (Figure 5, [5]). The optimization task can then be formally described by:

$$\min_{\boldsymbol{x}} \boldsymbol{c}^T \boldsymbol{x}$$

such that

$$\boldsymbol{A}_{eq}\, \boldsymbol{x} = \boldsymbol{b}_{eq}$$
$$\boldsymbol{A}_{ineq}\, \boldsymbol{x} \leq \boldsymbol{b}_{ineq}$$
$$\boldsymbol{x}_{lb} \leq \boldsymbol{x} \leq \boldsymbol{x}_{ub}$$

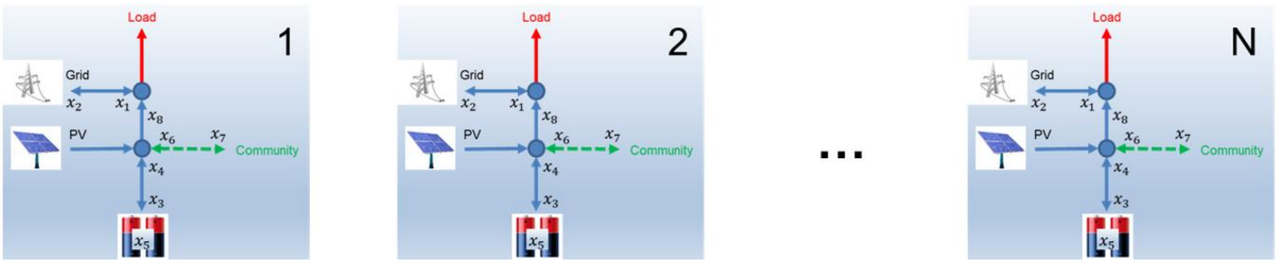

Figure 5: Combination of *N* participants in an electrical energy community (without heat exchange and sector coupling).

The possible energy situation of each participant of the energy community is depicted as discrete power flows with time instants of 15min.

Model for electrical and thermal energy

This general participant structure (Figure 6) allows to map all possible energy flow situation and calculate costs for purchasing energy and feed-in, both for electrical and thermal systems as well as sector coupling from Power2Heat.

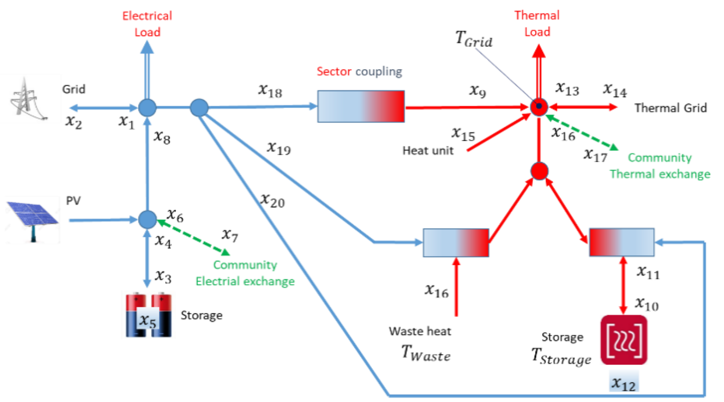

Figure 6: InduGrid participant structure for optimization including thermal energy and sector coupling

A combined optimization of electricity and thermal grid requires a sector coupling element to directly transfer electricity to heat. Additional sector coupling elements are required to adjust the temperatures. If for example, the available waste heat temperature is less than the thermal grid temperature, $T\_Waste<T\_Grid$, the waste heat must be increased to be useful. There are use cases, when the additional sector coupling elements are inactive, for example if the storage temperature is higher than the grid temperature, $T\_Storage>T\_Grid$.

Figure 7 provides an overview of the variables, used in the optimization structure.

x_1	Energy purchase from el. grid	x_8	Energy	x_{15}	Th. energy produced from local heat unit
x_2	Energy sold to el. grid	x_9	Th. energy transferred from el. part	x_{16}	Th. energy purchase from community
x_3	Energy to el. battery	x_{10}	Energy to th. storage	x_{17}	Th. energy sold to community
x_4	Energy from el. battery	x_{11}	Energy from th. storage	x_{18}	El. energy used for sector coupling
x_5	State of charge el. battery	x_{12}	State of charge of th. storage	x_{19}	El. energy used to adapt T_{Waste}
x_6	Energy purchase from community	x_{13}	Th. energy purchase from th. grid	x_{20}	El. Energy used to adapt $T_{Storage}$
x_7	Energy sold to community	x_{14}	Th. energy sold to th. grid		

Figure 7: Used optimization variables

Optimization methods allow evaluating the possibilities to share energy between the possible partners. Besides time-series of weather parameters and evolution of energy prices, optimization methods need historical data of energy flows (energy profiles): mainly energy consumption along time. Usual energy profiles cover at least a whole year to detect seasonality effects, and they have a 5–15-minute resolution.

3.2.3 General assessment of energy communities

To support the development of business cases, a general mathematical method [6] has been supplemented and expanded to assess the contribution of every participant in an (renewable) energy community [7] [8].

This development was necessary, since some generic cases show that in some unfavorable constellations some participants of an energy community must pay higher prices for energy in a community compared to an operation without the community. This can happen since the mathematical optimizer finds the lowest cost for the overall community and does not consider the individual cost. Further details are provided in Figure 9.

The devised method for equitable distribution of economic benefits is rooted in a process wherein the economic savings of communities are computed both with and without the involvement of the specific participant [5]. This information is then used to establish a "contribution index" for each participant. By integrating this index, the optimization process for energy exchange considers minimum savings, thereby ensuring an equitable distribution of community [7].

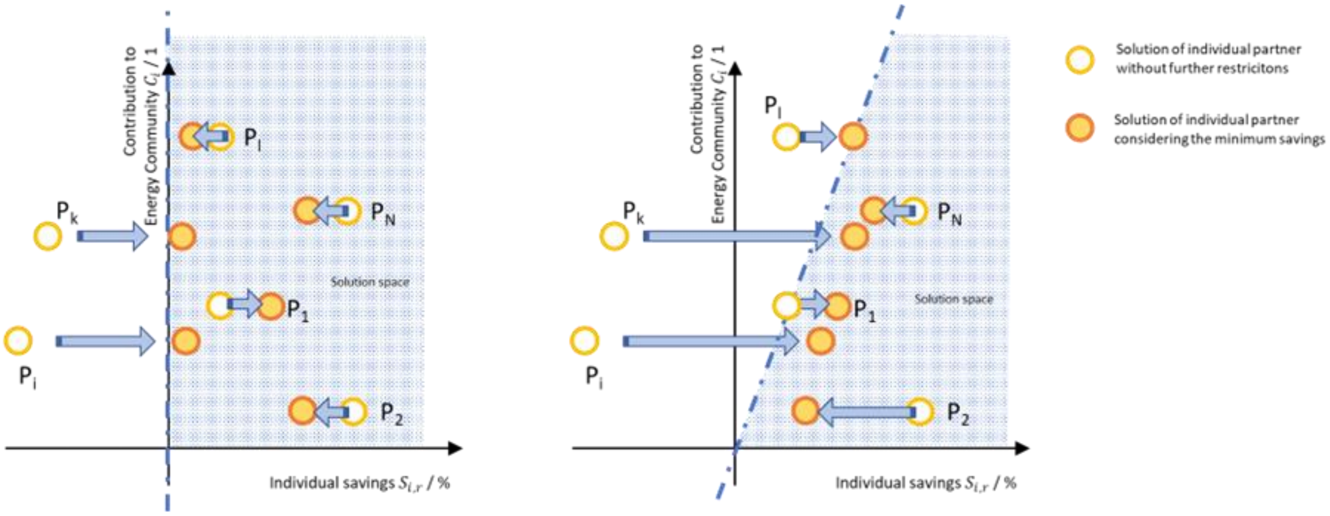

Figure 8: Restriction of the solution space for the optimization procedure ([7])

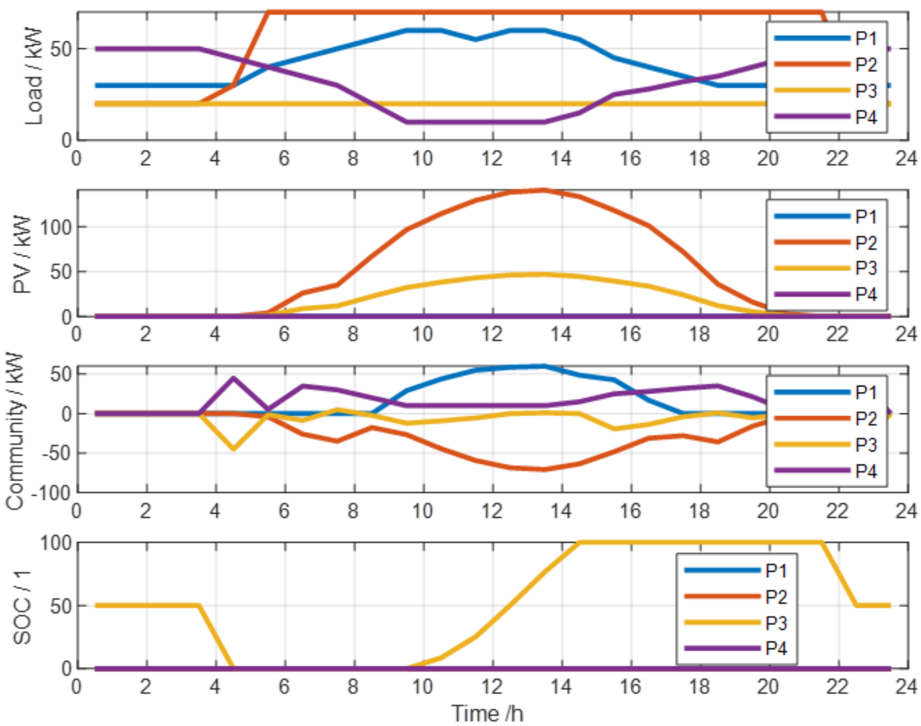

Figure 9: Results of the optimization of an energy community with four participants (from [5])

3.2.4 Web based user interface

Tailored information to the users is a decisive factor for the fashion in which the users perceive the provided information. User Interface serves as the crucial link between the system and the user. From the users' perspective, the page is cleanly organized into three panes to help users interact with questions while simultaneously having visual feedback of such interactions. The page provides a summary of the question on the left. For simplicity, this has been addressed as 'Cards'. Cards provide an interactive indexing mechanism to the asked questions with a summary of the question and an option to save the question to answer later. Users can navigate between questions, search for a particular card, or filter them based on various criteria. The interaction elements required for recording the user response are encapsulated in a section, hereafter named as 'Tiles'. These tiles are displayed in the center column. The system selects and arranges the required elements of interaction into a tile. The right column exhibits additional information, whenever required. For instance, it provides visual feedback of user-uploaded profiles or geographical representation when the user selects his address. Figure 10 portrays a screenshot of questioning page.

An intuitive web-based interface was designed after multiple deliberations. We developed a platform to tackle all these problems using a novel multi-disciplinary approach. We adopted chat-bot type approach to provide personalized experience, which in turn requires minimal input from the users.

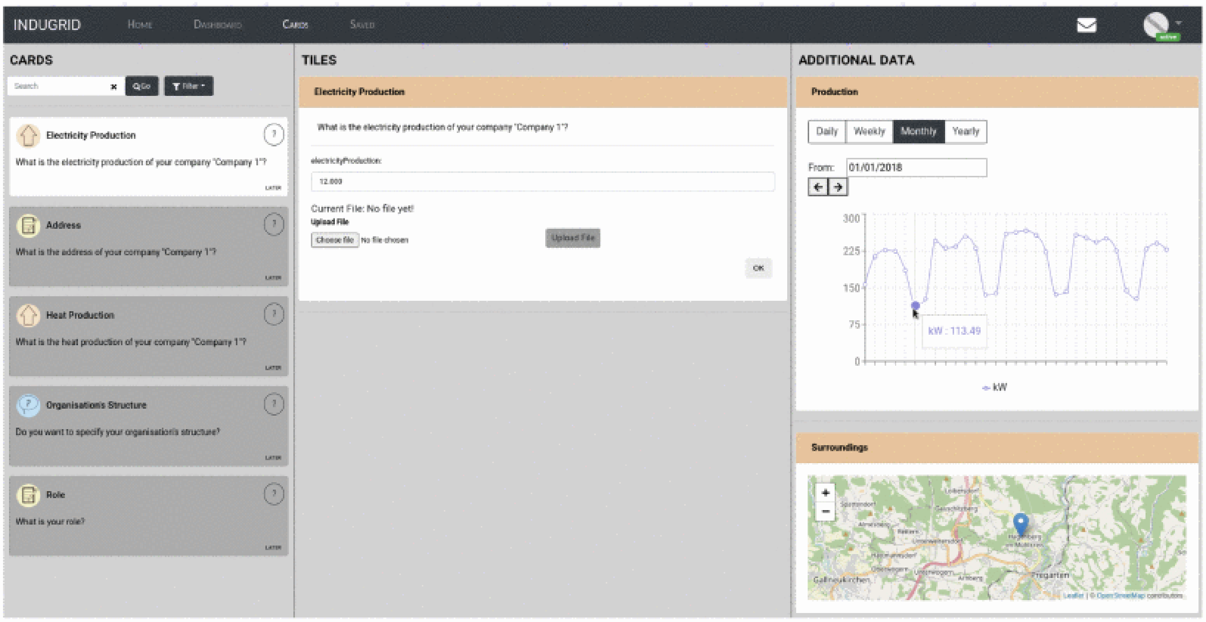

Figure 10: Questioning page

The designed platform makes a significant departure from the traditional approach of using long static forms as questionnaires to request information from users. These static questionnaires have a fixed structure and sequence of questions where all the required pieces of information are shown together to the user. This negatively impacts the user experience as the user tends to perceive that the system requires a lot of information and efforts to fill the data input fields in one go. To avoid user discouragement, we designed the system to provide anthropomorphism which also serves as the basis of chat-bots. The system displays one question at a time and motivates the user to provide the required piece of information. Users can respond to each question by answering, skipping or saving it to answer later. Once the system gets the user response, it selects the next question to be asked which can be regarding (a) the structure of the company (as depicted in Figure 11 and Figure 12 where the platform creates the structure and provides a visual feedback); (b) the values to the parameters of user-selected components; or (c) general information. Additionally, the platform leverages the Zeigarnik effect to encourage users to provide more information by displaying the saved questions again during the next session.

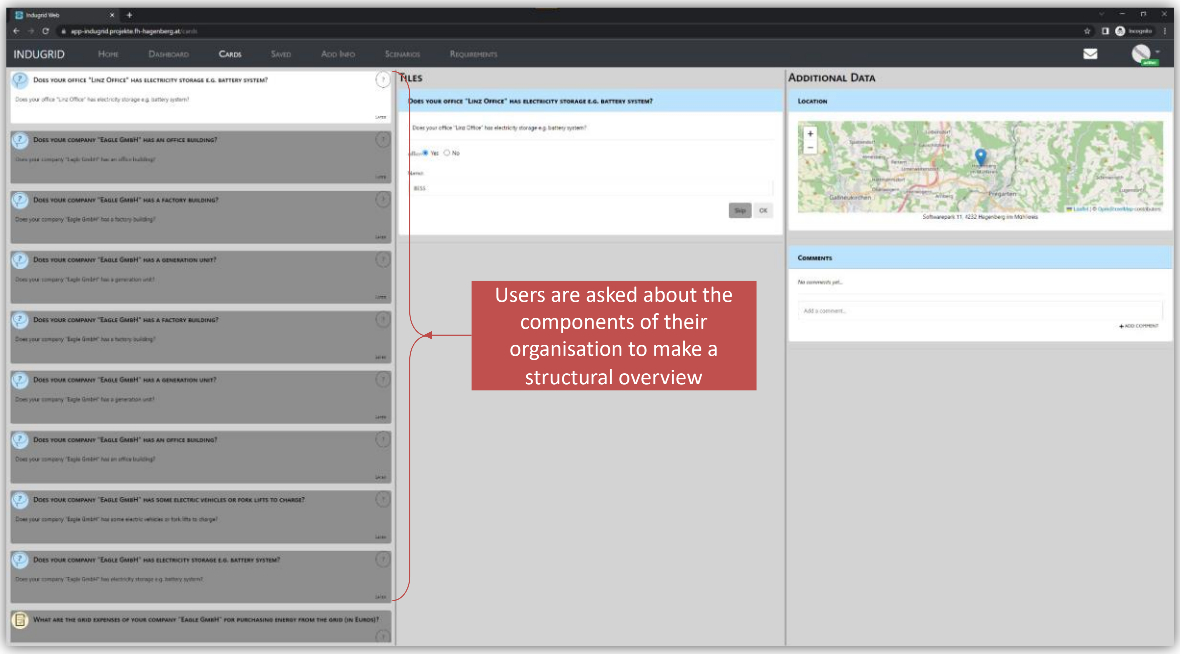

Figure 11: Organisation of the company

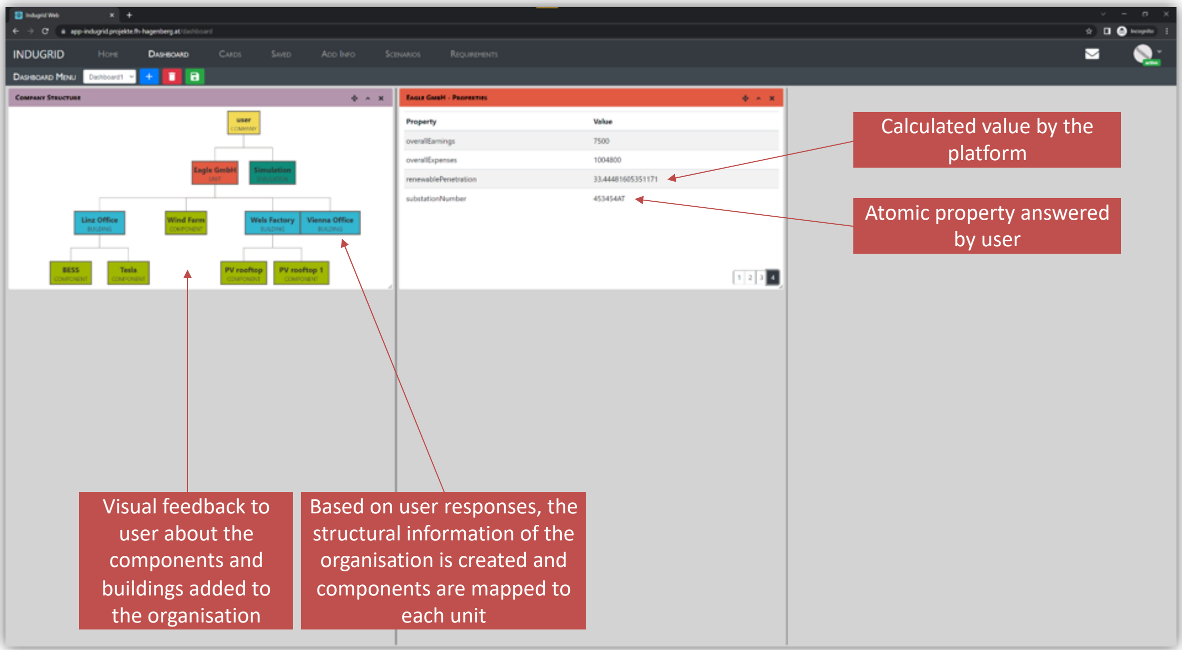

Figure 12: Structure of the company

The users can answer the questions based on the readily available information with them at the time of answering. For instance, the users can choose to answer the aggregate electricity production which could be scaled on the generic profile or the user could also choose to upload the production profile for more refined results. This is depicted with the help of Figure 13.

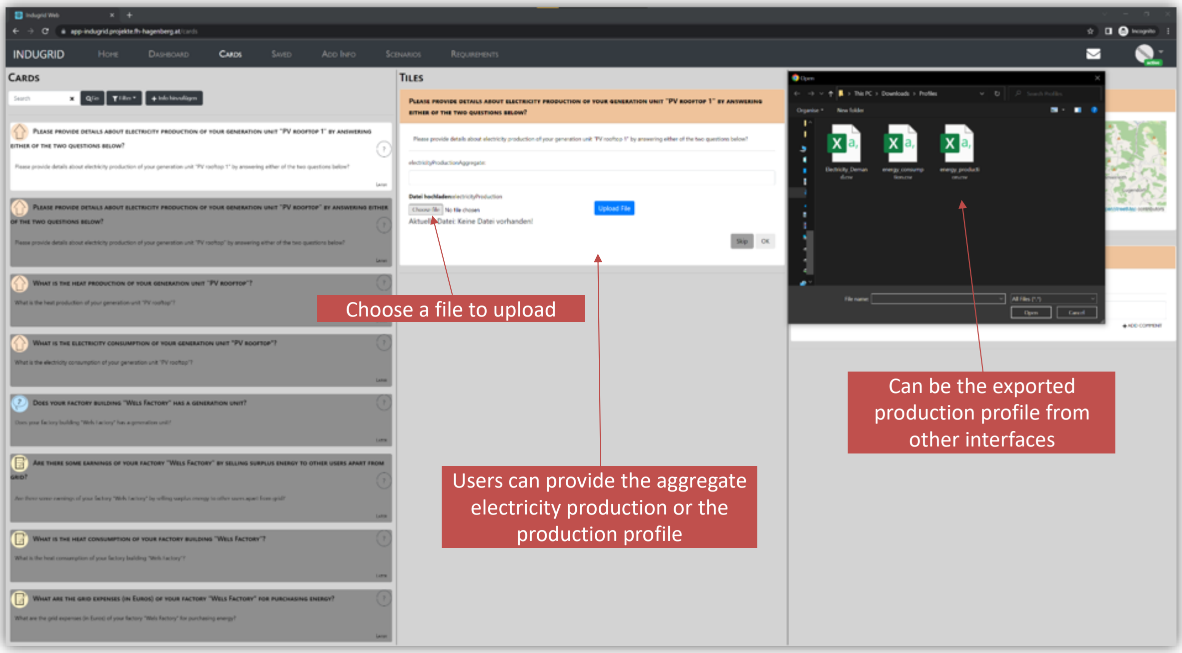

Figure 13: Upload of aggregated electricity production file

Users can design their own dashboard as shown in Figure 14 where the relevant information can be viewed at a glance. This might include the information they provided directly using multiple questions or the information the system calculates or deduce based on the information state provided by the users.

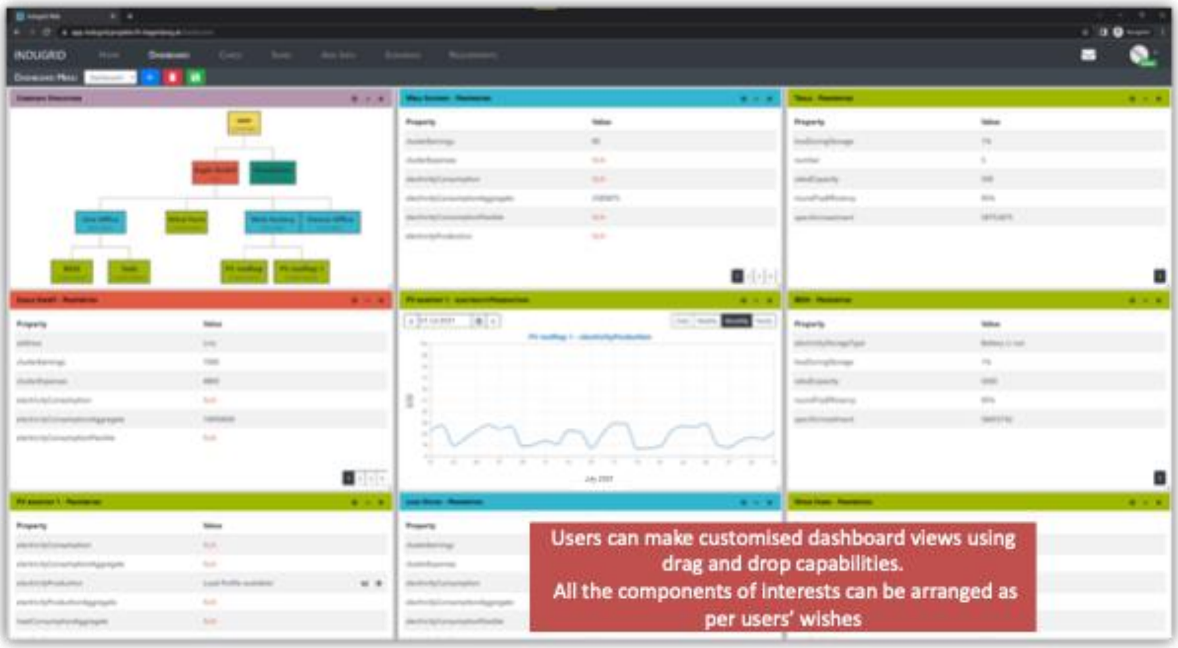

Figure 14: User dashboard

Most companies find it very critical to provide detailed data of their loads and internal processes. As this data can reveal strategic information about the companies, they usually classify it as confidential.

This confidentiality question avoids any data availability and hence makes the use of the exchange platform unusable. Data management strategies to avoid this obstacle were developed.
Two approaches based on data reduction methods should motivate companies to share their data. The objective of data reduction methods is to provide profitable information without giving all the details that they could consider critical.

The first method considers the energy information of one sample working day and one sample weekend day per week of the year. The second method requires one sample week per month.
Companies must reduce the information and provide it as input for the exchange platform.
Both methods were tested in a community of 18 participants under different conditions and compared against a year simulation.

If storage systems are not present in the community, the differences between both reduction methods are minimal. In this case, the first method (one day per week) provides results faster because it computes two optimizations per week (one for the sample working day and one for the sample weekend day). The second reduction method (one week per month) achieves slightly accurate results, but it is time demanding because it carries out one optimization every 15-minutes per week.

By using storage systems, the first reduction method seems to be unsuitable because it cannot track the state of charge (SOC) of storage systems for more than 24 hours. As the second method does not have this limitation, it has access to a wider space of optimal solutions and hence, it provides much better results than the first reduction method.

The analysis of the results of the reduction models considers two aspects:

- the accuracy of the values, and
- the computation speeds.

In the current situation, the majority of the industrial partners do not have storage systems and share energy from different sources. For this reason, the configuration of the experimentation is set up to cover this case.

Objective functions include dynamic market prices of energy not only from external energy providers but also trade prices inside of the community. The prices also consider grid fees.

As previously pointed out, the experimental environment considers an energy community with 18 participants without energy storage systems. Energy prices can be different for each participant, not only inside of the community but also the costs derived from utility operators and providers.

The numerical results of both reduction methods vary depending on each community participant in a range of 5-30% concerning the not-reduced optimization, which provides the lowest costs. The computation time needed for each method varies enormously: the not-reduced data optimization takes over 135 minutes, and the reduced data methods 3 and 8 minutes, respectively. As data reading consumes a considerable time, the amount of data to read is not a minor issue. The number of optimizations that each method needs is the most relevant factor in speeding up the computations.

Despite the lower quality of the results of the data reduction methods, these allow finding matches between the participants and detect candidates to share energy. Moreover, a shorter computation time can motivate the participants to provide more detailed data in a second step.

3.2.5 Energy exchange platform

By a questionnaire method, basic company data as well as yearly consumption and generation data are gathered. Based on that information the partners delivered detailed (15 min) generation and consumption profiles (e.g. in Figure 15). Additionally, the potential for demand side management was evaluated. Especially the load for charging of in-house transportation (fork lifts, …) can be an ideal subject for load shifting.

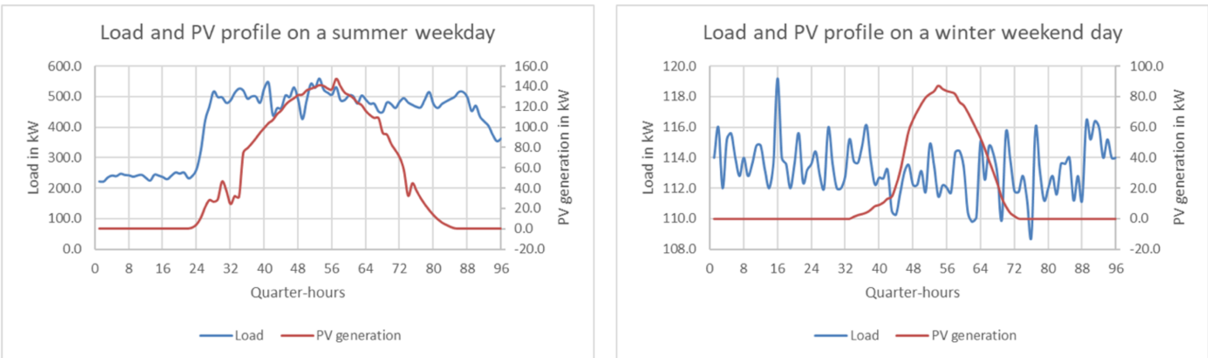

Figure 15: Load and PV generation profile for a summer (left) and winter (right)

A dedicated dashboard has been designed to provide a bird’s eye overview to users with customizable deck. The platform provides users the much-needed freedom to choose their view, which can be selected from several available blocks. These include, inter alia, the blocks for getting the visual feedback of company structure, the information provided by the user, properties and parameters corresponding to each component, interim as well as final results, and data visualization of the respective components.

Figure 16 exhibits a screenshot of the designed dashboard. Users are allowed to customize their view by selecting the relevant tiles, minimizing these tiles or deleting them. This provides easy dissemination of information to users while focusing on the data which is most important for them at a particular point of time. Users can make multiple dashboards which each having a different view to serve for different needs. The default view illustrates the company’s structure as defined by the user. This provides the outline of all the components attached to the user. Each component corresponds to various parameters which are summarized in the respective tiles. These can be changed in the dashboard, or the user may prefer to switch to cards-tile view to change the values, if required. Moreover, dashboard provides the interactive charts to visualize the time-series data including consumption and production patterns.

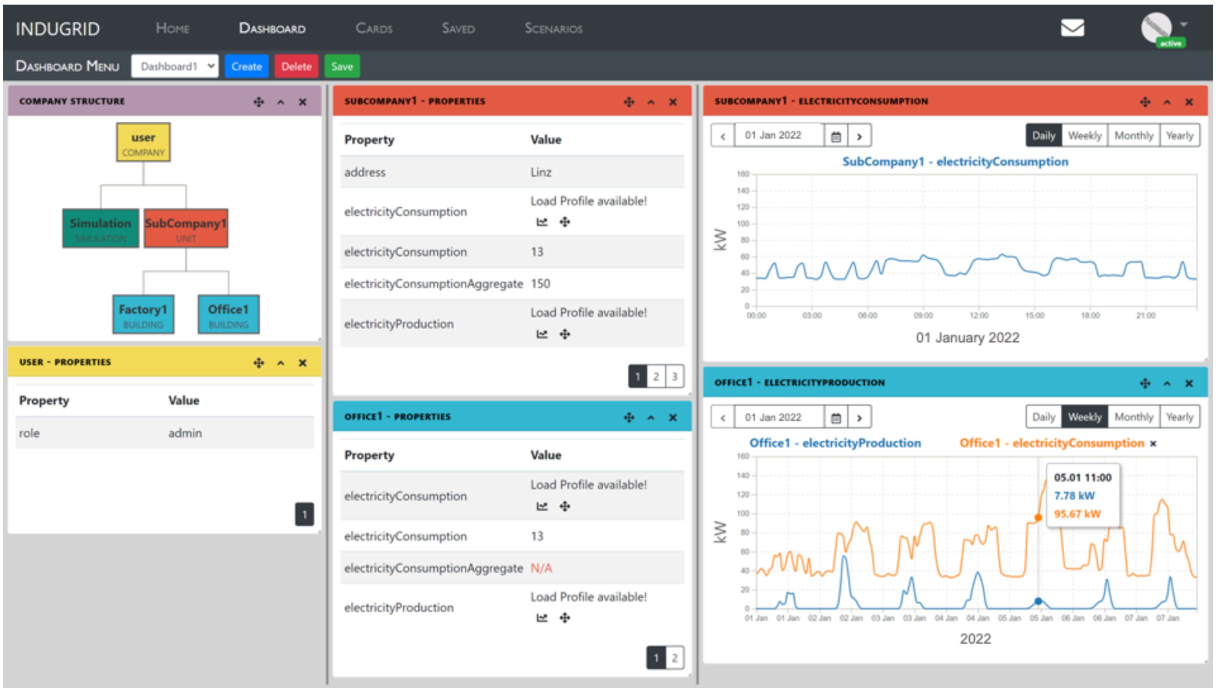

Figure 16: Screenshot of the Dashboard customized by the user, where each tile can be moved, minimized or removed as per the wish of the user to customize the view. Dashboard also capable to serve the dynamic demands of the users by allowing them to add new tiles

Visualization in Energy Maps

As already established, the process of identifying and conceiving energy sharing depends heavily upon the information collected from the users. Conventionally, this process of information collection is conducted using long questionnaires and tedious survey exercises. However, it is often witnessed that the response rate of the user and the length of the questionnaire are negatively correlated to each other. This makes the task of the users a cumbersome process while tackling with long static questionnaires [9] [10] [11].

The designed platform for InduGrid makes a significant departure from the traditional approach of using long static forms such as questionnaires to request information from users. These static questionnaires have a fixed structure and sequence of questions where all the required pieces of information are shown together to the user. This negatively impacts the user experience as the user tends to perceive that the system requires a lot of information and efforts to fill the data input fields in one go.

To avoid user discouragement, InduGrid was designed to provide anthropomorphism, which also serves as the basis of chat-bots. The system displays one question at a time and motivates the user to provide the required piece of information. Furthermore, InduGrid platform has been designed by using cross domain knowledge from psychology. Leveraging foot-in-the-door method of consistency principle of psychology, the platform dynamically asks only the pieces of information which may lead to conclusive results. This helps in increasing the probability of getting the required information from the users. The selection of questions is based on user-behavior and the relevance of the information being sought. As the questions to the users are asked dynamically, the system provides a tailored experience with higher user retention.

As depicted in Figure 17 the system forms different combinations of the users into finite clusters. A cluster is defined as a group of minimum two companies having complementarity profiles for energy sharing. One company can be a part of multiple clusters but cannot be included multiple times in the same cluster. The parameters required for clustering are already in place, including the production profile, consumption profile, geospatial information and the substation which is responsible for the physical connection to the company. The information of the connected substation is key to understanding the feasibility of the proposed cluster on physical grid layer.

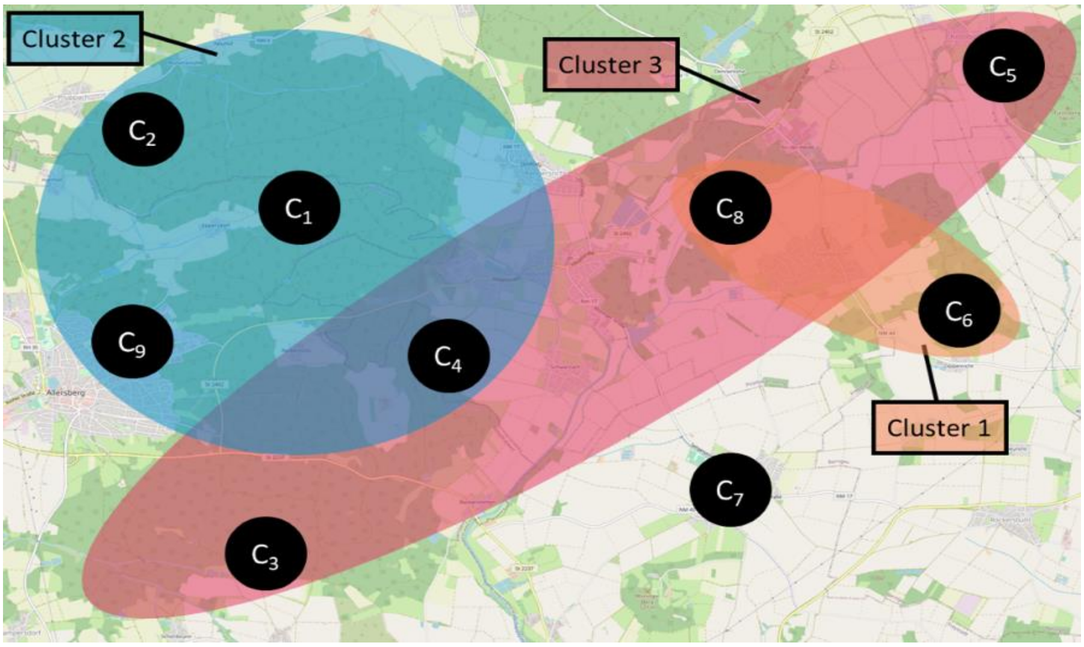

Figure 17: Clustering of companies (Cx) based on technical, economic and legal feasibility. A company can be a part of one or more clusters [12]

Figure 17 explains the clustering with an example showing some companies in the same geographic vicinity having complementarity energy, indicating a possibility of energy sharing. At a particular instance of time, when the system does not find C7 to fit into any cluster, then it does not ask more information from the corresponding user as that may not lead to a conclusive result. However, the energy landscape is dynamic with respect to the technical, legal, and business boundary conditions. Therefore, the conditions which make C7 a misfit into any cluster may change over time. As the system is competent of re-examining all the plausible solutions, it can notify the user if the earlier non-compatible partner can now lead to a feasible cluster, for instance C7 fits into any cluster, with the change in the boundary conditions. This will lead to the system asking for more information from such users to evaluate and reflect the present situation.

All the possible combinations of energy sharing users in a cluster are evaluated by stratifying the solutions based on available user-data. First stratum, the initial solution space, is envisaged to provide preliminary results and the accuracy of results is improved with each progressive stratum. Once the users find an interesting solution, they can provide more information to improve results by proceeding to the next stratum. All the plausible solutions are saved in the solution space which is further evaluated over time as and when a condition is changed in technical, economic and legal dimensions. When a considerable change occurs in one of the dimensions, the system notifies the concerned users. Evaluation of all the strata over time enables us to reflect the current solution space rather than continuing with just the solutions which were profitable at the time of initial investigation. The process of stratification is outlined in Figure 18, where Stratum 1st corresponds to the initial solution space containing all the plausible cluster combinations. These solutions are iterated with more data provided by users to reach Stratum nth, where each progressing stratum increases the accuracy of results and discards the clusters which are found inconceivable due to infringement of boundary conditions. These solutions are evaluated at time t1, but as technical, legal and economic conditions change with time, the system reworks n times for nth change, represented by the iteration at time tn.

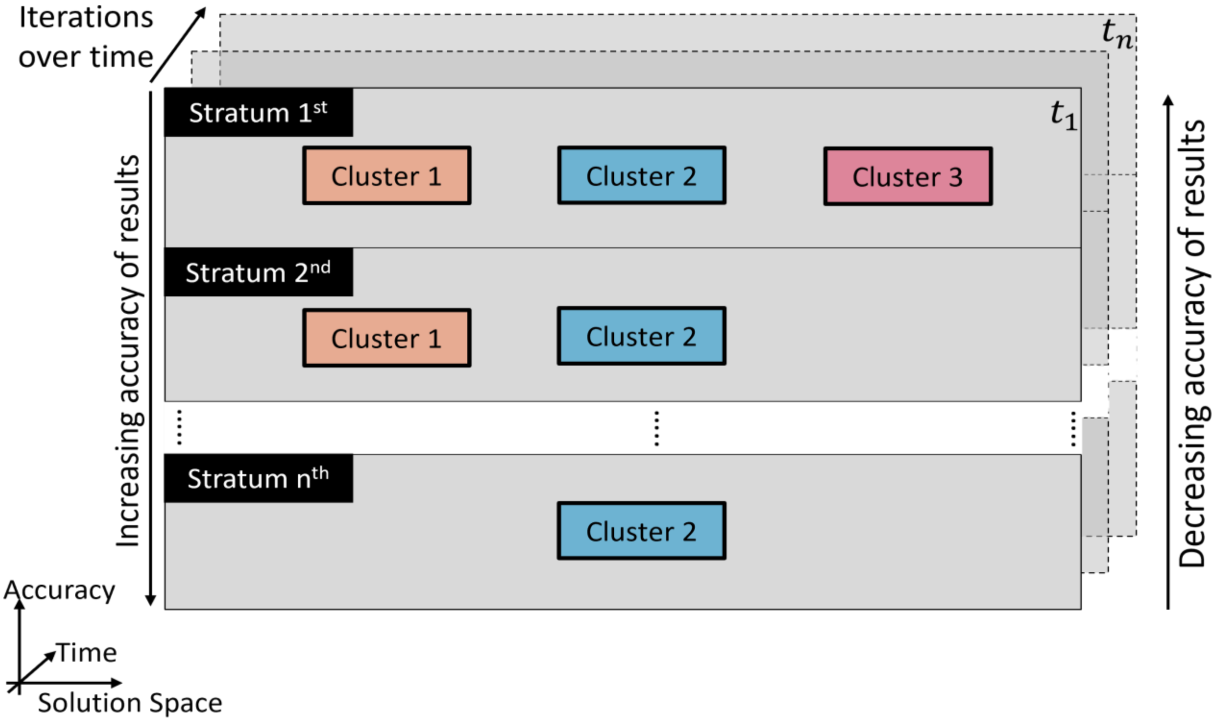

Figure 18: Stratification depicting evaluation of different potential solutions, where Stratum 1st denotes the initial solution space. Accuracy of these solutions is increased with more user information. The process of evaluation is reiterated overtime to reflect

The discussed process of stratification and different scenarios are implemented with the help of a dedicated section for comparing the results of the aforementioned. The tab with 'Scenarios' is illustrated in Figure 19, where the users can access the summarized view of the properties associated with a scenario, compare different scenarios, create a new scenario and so on. This functionality is also used for making different sets of energy sharing partners and comparing their results to find the best suited one for the energy community. As and when the boundary conditions change, the new plausible scenarios are populated in this section of the platform.

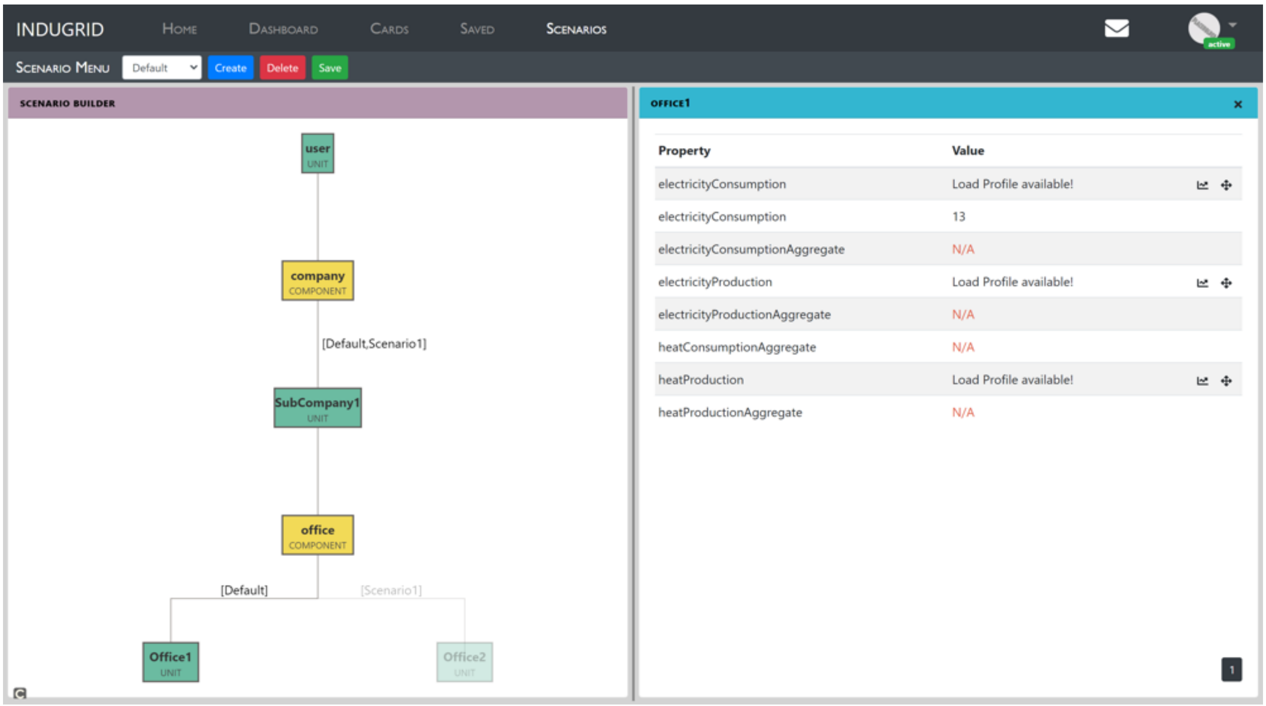

Figure 19: A dedicated mechanism to compare various possible scenarios and summarizing their respective associated parameters

Apart from providing the visual feedback (Figure 20) to the users about their chosen location, maps also serve as a tool to summarize the scope of energy transactions. As depicted in the attached image, the map corresponds to the location provided by the users in real-time. This ensures the minimization of the scope of human errors while providing the details. These geo-spatial details enable the system to find potential energy sharing partners in the vicinity.

Contrary to the original plan to access the DORIS map material, OpenStreetMap was ultimately used. This decision is based on the fact that, on the one hand, relevant data (e.g. grid based data) for identifying partitions was also not available in DORIS and, on the other hand, the geographical restriction of the available data represented a considerable limitation.

Once the potential energy exchangers are identified using the geo-spatial information with the help of maps, the system forms different combinations of the users into finite clusters. A cluster is defined as a group of minimum two companies having complementarity for energy sharing. One company can be a part of multiple clusters but cannot be included multiple times in the same cluster. All the possible combinations of energy sharing users in a cluster are then evaluated by stratifying the solutions based on available user-data. The clusters on the map represent the potential combinations of plausible energy communities.

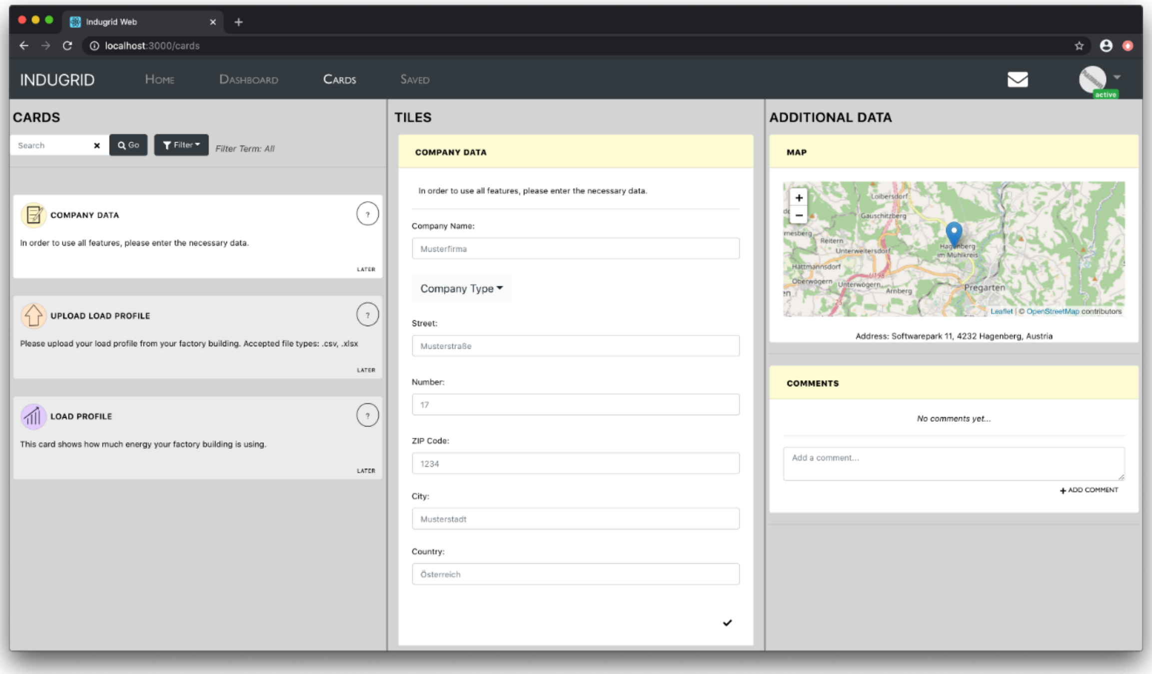

Figure 20: InduGrid Dashboard

3.3 Testbeds and their business cases

The energy exchange platform developed in section 3.2 was utilized for the economic evaluation of energy communities with diverse participants and various forms of exchange.
The platform was tested with participants at several locations and used as a tool to support the planning of energy communities. As part of the project, several energy communities were successfully implemented. However, for other concepts, it was determined that economic viability could not be guaranteed, leading the operators to decide against their implementation.

The platform's ability to assess the economic feasibility of energy communities with varying participants and exchange methods has been demonstrated through testing with participants at multiple locations. This has provided valuable insights into the successful implementation of certain energy communities, while also highlighting the challenges and limitations faced by others.

All the sites considered in this project are located in Upper Austria (Figure 21), the following energy exchange options were analyzed in detail:

- Test site Ennshafen: thermal energy exchange
- Test site Wels 1: electrical energy exchange
- Test site Wels 2: Citizen’s energy community
- Test site Wels 3: thermal energy exchange
- Test site STIWA
- Test site Hagenberg 1: thermal and electrical energy exchange

Figure 21: Locations of the different test sites

3.3.1 Test site Ennshafen – thermal energy exchange

An initial evaluation of the energy cooperation possibilities in the Ennshafen industrial park revealed potential for cooperation between the company Salesianer Miettex (formerly Wozabal Miettex, as heat supplier) and the neighboring company Biomontan (as heat consumer) - see Figure 22.

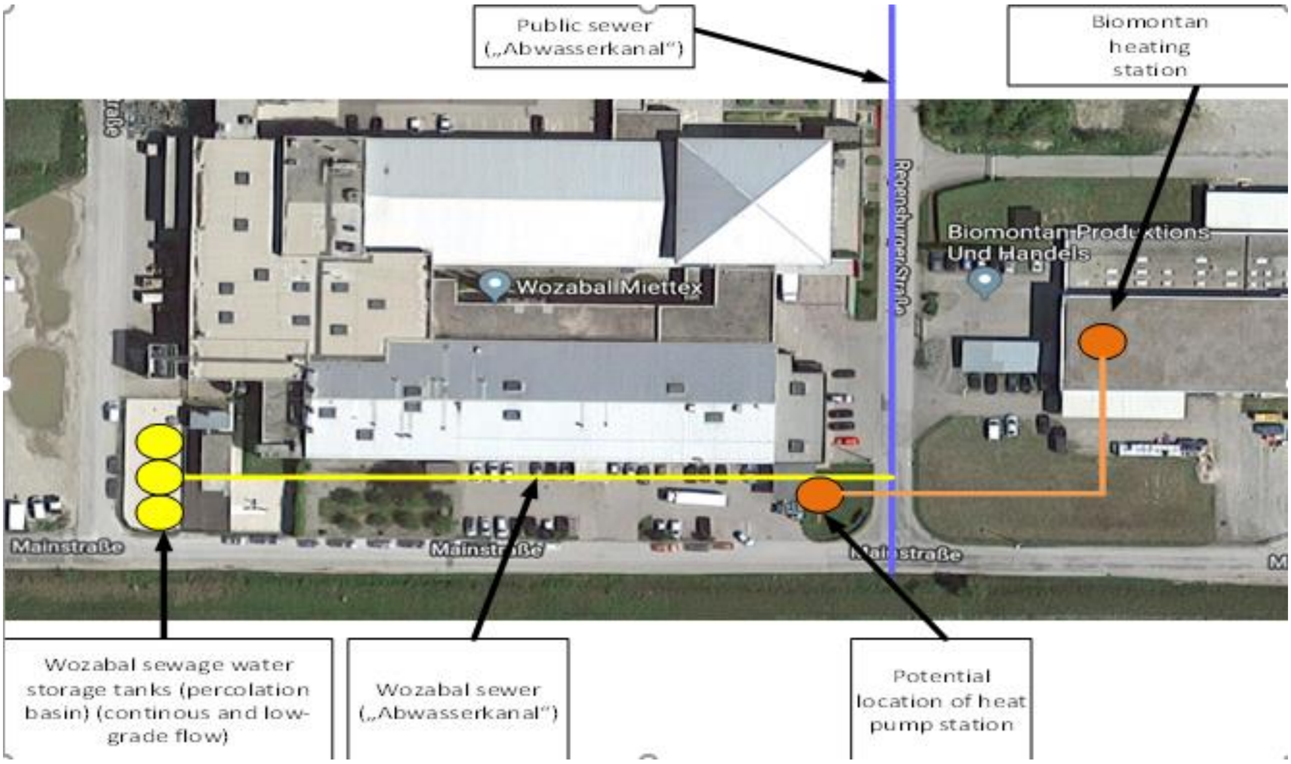

Figure 22: Initial situation at testbed Ennshafen

To estimate the potential for a successful heat exchange, an analysis of both the available waste heat (quantity, availability and temperature level) and the heat demand (load profile and existing heating system) was carried out.

It was determined that the heating energy requirement of the neighboring company Biomontan is around 300 MWh per year. The existing heating system there operates with a flow temperature of around 50°C to 55°C and is therefore very well suited to the use of a heat pump with a high coefficient of performance (COP).

The fact that the wastewater from Salesianer Miettex is consistently available at temperatures between 30°C and 40°C has proved to be an advantage, which fits in well with the operating requirements of the heat pump (see Figure 23).

Initial analyses and estimates also showed that the amount of wastewater is sufficient to cover the demand, which suggests great potential for effective waste heat recovery and utilization.

Figure 23: Shafts of the waste water system and waste water temperature measurement at Salesianer Miettex

At the inception of the project, the neighboring company's CO_2 emissions stemming from natural gas heating were recorded at a significant 62 tons per year. However, with the potential adoption of a heat pump for electricity consumption, the projected CO_2 emissions would be substantially reduced to a mere 12.3 tons annually in the event of project realization. This transition would result in a substantial net CO_2 saving of up to 49.7 tons per year because of the collaborative efforts.

Moreover, throughout the project's duration, photovoltaic (PV) installations have been integrated into the operations of both companies, further enhancing sustainability efforts.

In the technical planning phase, thorough investigations were conducted to explore two distinct possibilities for the placement of the heat pump, as illustrated in Figure 24 and Figure 25.

It is important to note that while the overall capital expenditure (CAPEX) for both configurations is assumed will result in comparable costs, various other critical factors such as technical implementation complexity, maintenance and operational requirements, and indirect considerations including marketing opportunities, differ significantly between these two options.

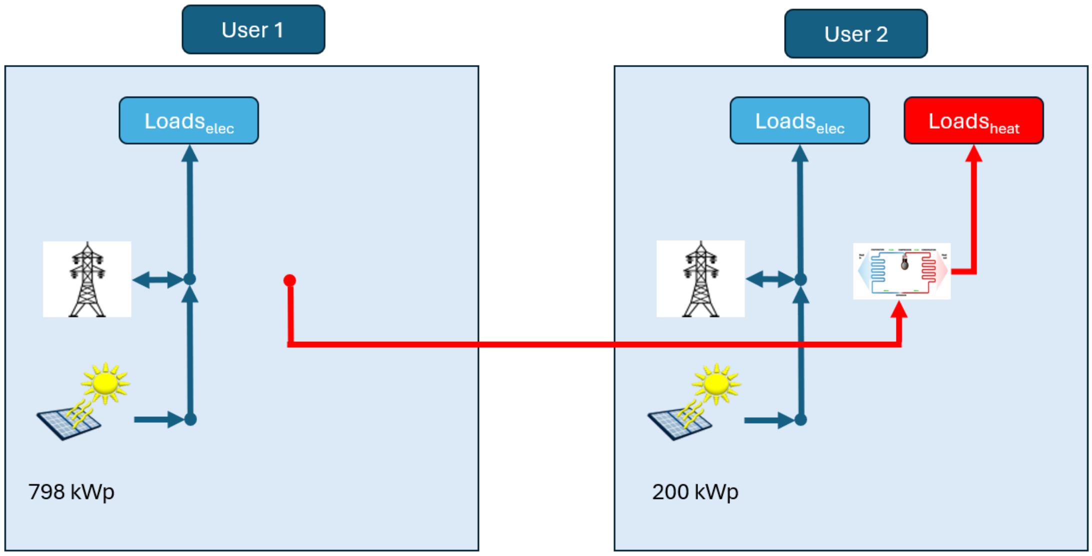

Figure 24: Schematic description of the energy flows, heat pump operated at Biomontan as heat consumer

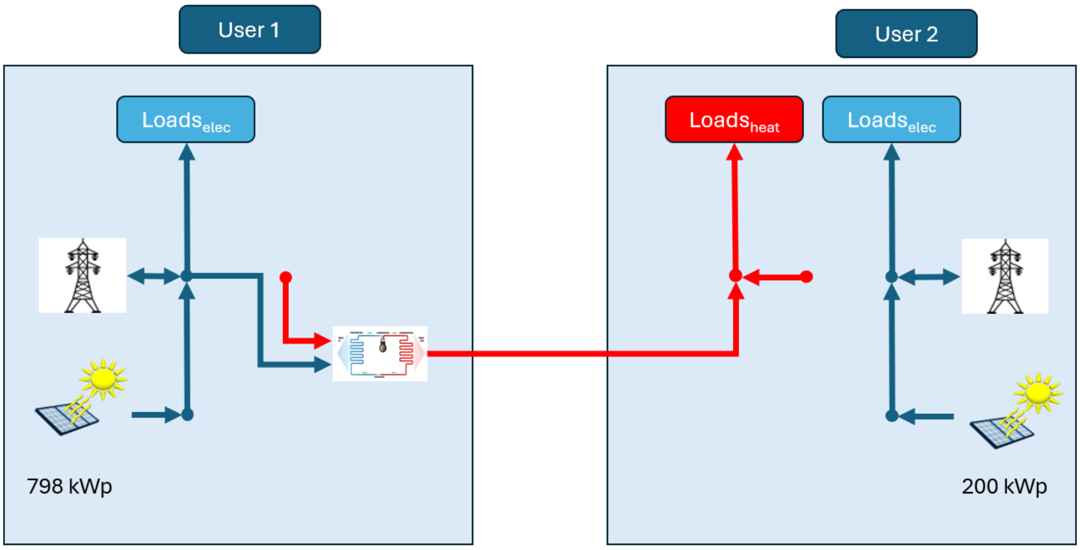

Figure 25: Schematic description of the energy flows, heat pump operated at Salesianer Miettex as heat supplier

Both possible configurations were analyzed with the energy exchange platform from Chapter 3.2, using annual consumption data and simulated PV gains as well as historical ambient temperature profiles and assumed waste heat temperatures. The optimization algorithm (optimization of energy flows to minimize operating costs for the heat supply of Biomontan) led to optimal energy flows, Figure 26 shows the collection of monthly and annual results.

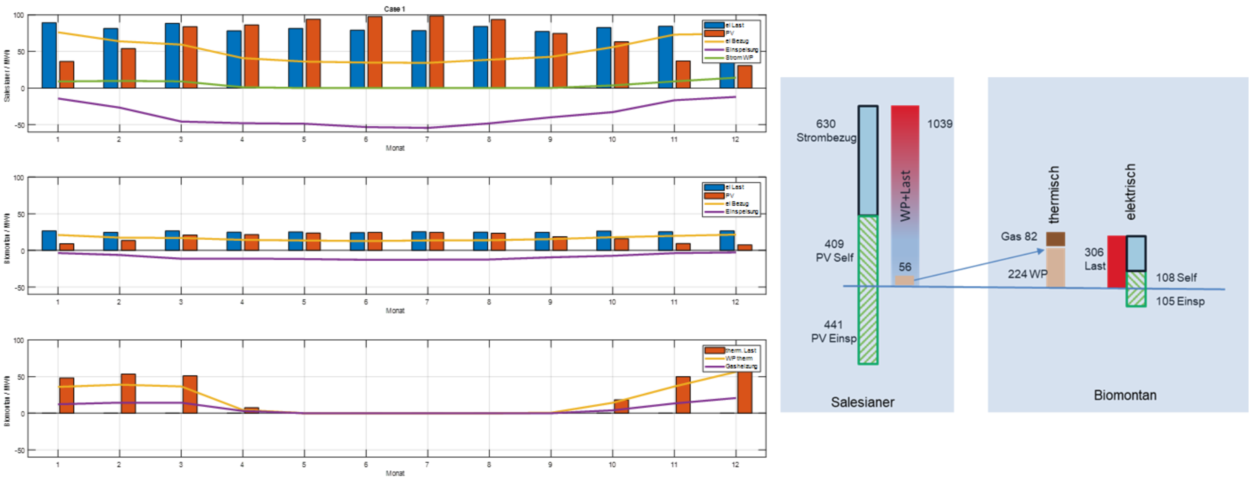

Figure 26: Monthly (left) and annual (right) energy flows between Salesianer Miettex and Biomontan

Business case evaluation and findings

In addition to the technical considerations, potential risks for the business case at this test bed have been thoroughly examined. These include the possibility of unfavorable outcomes in contract negotiations, the unavailability of subsidies, and the potential for limited benefits from cooperation on one hand, as well as certain interdependencies on the other. [13]

Following the collection of simulation results and the identification of non-technical boundary conditions for this test case, a comprehensive techno-economic assessment was conducted. This evaluation provided essential operational parameters and ultimately revealed that the implementation is not economically feasible, despite factoring in current funding and extended payback periods.

As the results showed a negative economic feasibility and the remuneration of the waste heat supplier was minimal or even non-existent, it became clear that the implementation would not take place in the planned form.

During the project, alternative setups to those depicted in Figure 24 and Figure 25 were briefly explored, with the consideration of a ground-source heat pump as a potential option. Initial investigations suggested that this alternative could be cost-efficient. However, the installation of the ground-source heat pump at the customer's premises led to a decrease in the potential remuneration per kWh of waste heat, further diminishing the economic viability of waste heat co-utilization.

While escalating energy prices might enhance the economic feasibility of the original scenario, a comprehensive sensitivity analysis was conducted on payback periods, gas prices, CO_2 prices, and other relevant factors, all of which yielded unfavorable results. Subsequent to the unsatisfactory outcome of the economic analysis, the companies opted not to pursue the matter further.

The consortium also undertook a comprehensive analysis of the business model approach, aiming to clarify its applicability in basic waste heat utilization projects where users and suppliers are separate legal entities. The consortium identified several methodologies outlined in the literature but noted that these business model approaches primarily focus on identifying niches or combinations of actors, particularly in data-driven (non-asset) businesses. In contrast, within the established energy sector, which likely encompasses external waste heat provision, business models primarily revolve around straightforward profitability calculations.

3.3.2 Test site Wels 1 – electric energy exchange

In Wels a multilateral electrical energy exchange was build up in the form of a renewable energy community with the company Rübig and its small hydropower plant to supply surrounding consumers. Some of them are equipped with PV-systems, only a few of them with an internal storage unit.

Rübig, in collaboration with EWW AG as the utility manager, engages in the production of electricity from hydropower and assumes the role of a producer, supplying electricity to various users with diverse consumption profiles.

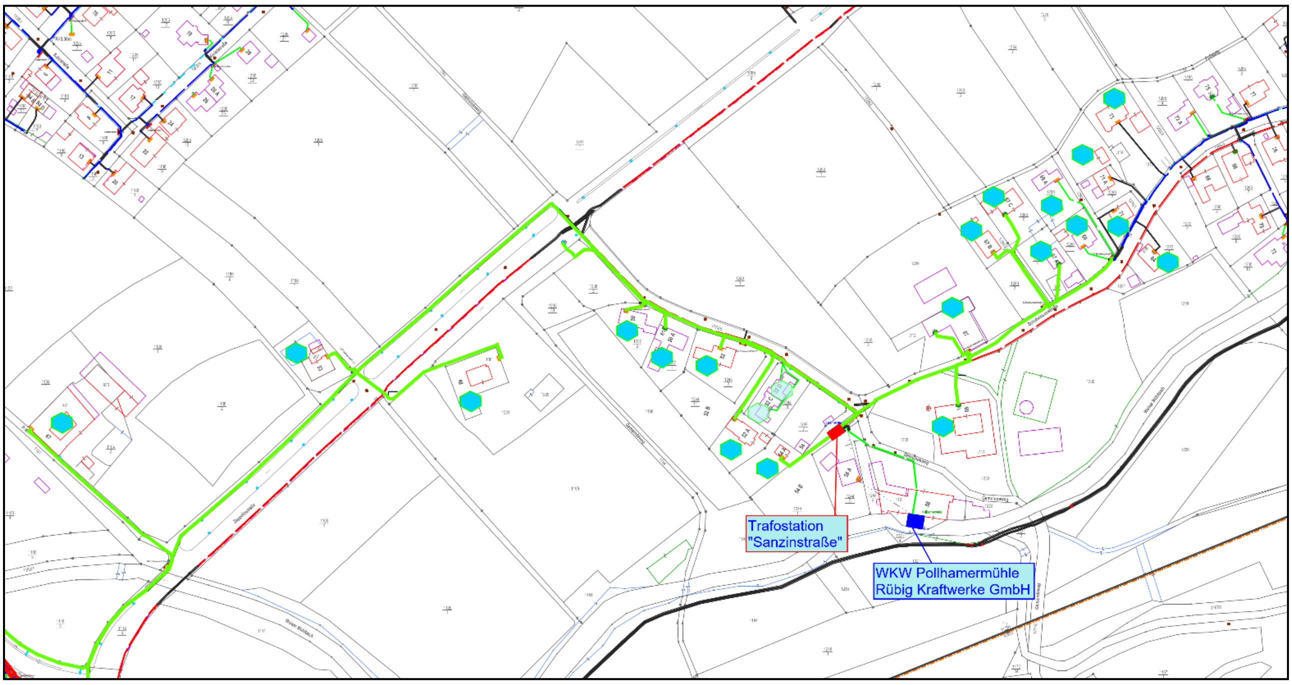

Figure 27: Overview map of the participants in the electrical energy community in Wels, Testbed 1

The legal possibilities for establishing renewable energy communities already existed at the time of implementation.
While many renewable energy communities have been established with photovoltaics (partly supported by home storage systems), the utilization of small hydropower plants as part of an energy community represents a particular novelty that was investigated in this project.

The contractual structure also had to consider the fact that the project partner eww Wels Strom could only act as a service provider and not as a participant within the energy community. The contractual relationships can be seen in Figure 27.

Business case evaluation and findings

Two different approaches were analyzed for the assessment of economic viability. In the first case, only one renewable energy source - the small hydropower plant - was assumed. In the second case, the possibility of feed-in from prosumers (end customers with PV systems) was also analyzed. It turned out that both cases allow economical operation for all participants and therefore a renewable energy community was founded. In the first phase, only the small hydropower plant was allowed to feed into the energy community; in a second phase, the participants themselves could also feed in.
The assessment of these business cases benefited from having historical production and consumption load profiles for all participants at a 15-minute time resolution..

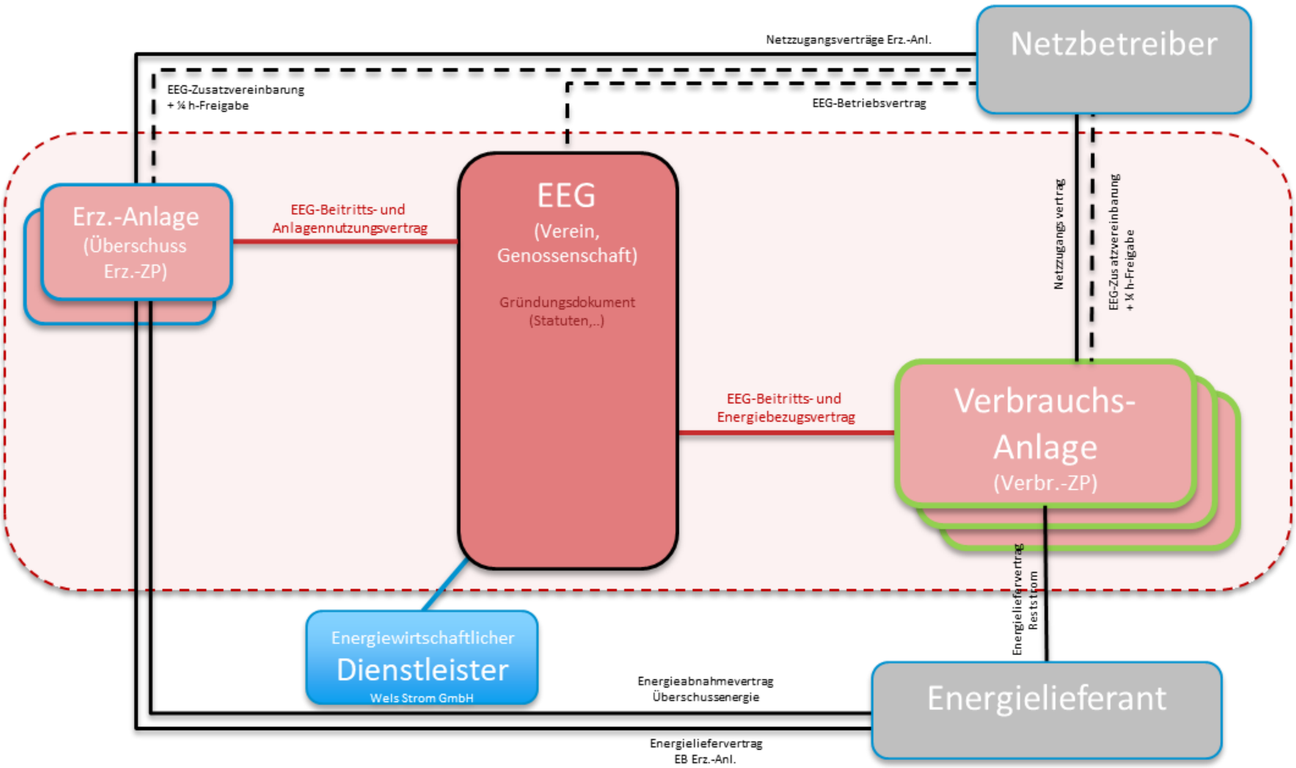

Figure 28: Legal relationships between various players in the renewable energy community

This renewable energy community with a small hydropower plant is very unusual and offers the rare situation that the energy source can cover most of the participants' needs almost all year round (Figure 29). However, this figure also shows that even this energy community sometimes needs electricity from the grid in the event of maintenance work on the hydropower plant (which took place in the last week of September 2022). Figure 30 shows a section of the course of a day.

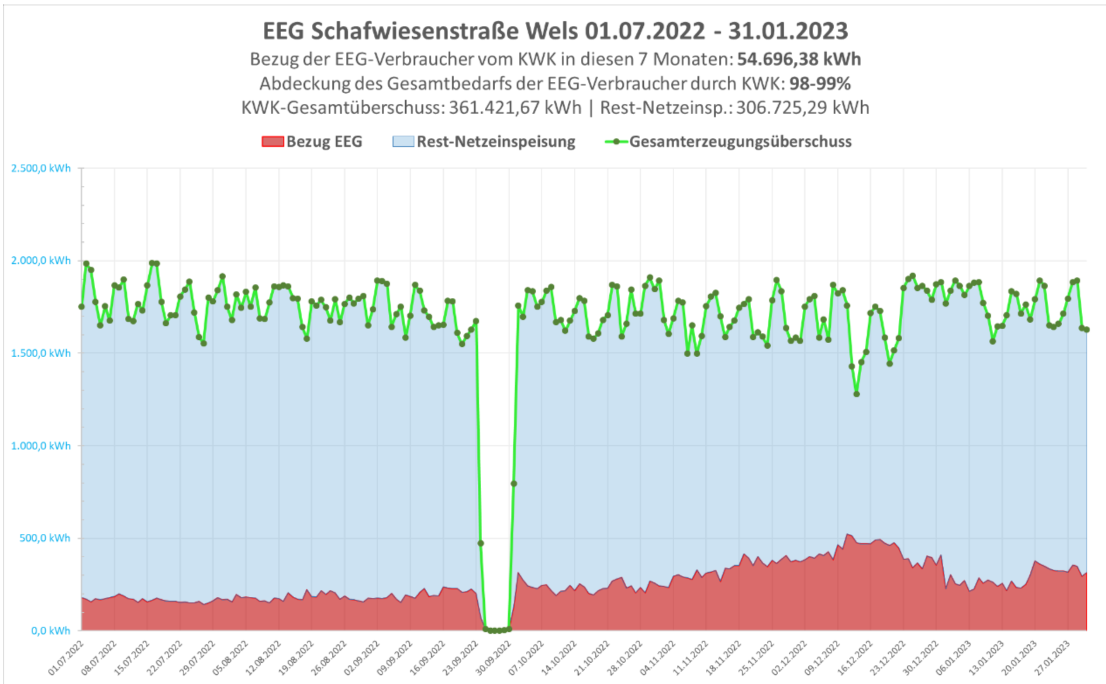

Figure 29: Results of operation of the renewable energy community. Green: production from hydro power plant, red: aggregated obtained energy from renewable energy community, blue: feed-in electrical energy

Figure 30: Course of the day (18.8.2022) of the energy production (green) and the load from the energy community (red)

3.3.3 Test site Wels 2: Citizen's energy community

The energy exchange platform from chapter 3.2 was also used to assess the economic viability of citizen's energy communities. The consideration of the legal frame of a citizen energy community has been necessary to include also large companies (as some project partners in Wels) in the electric power exchange via the public grid. Compared to renewable energy communities, the citizen energy community is not limited to grid net levels and has also no geographical restrictions – but the economic advantages (reduced grid fees, payments for eco investments, …) cannot be taken.

These more difficult conditions reduce the economic benefit for potential participants in energy communities. Nevertheless this use case was also investigated.

As an example for several configurations, the electrical power exchange between PBS (with connected companies) and Formatwerk was analyzed in terms of potential savings (Figure 31). Formatwerk has planned to increase the already existing PV size to supply also PBS with electricity within a citizen energy community.

Figure 31: Placements of Format Werk and PBS arounds Wels

Business case evaluation and findings

The economic viability strongly depends on the actual energy costs, which were significantly higher than the year before, 2020. This situation can lead to an economic operation of the energy community (and to an attractive return of investment of Formatwerk in PV).

The simulations with the energy exchange platform were carried out for variation of parameters

- PV-size
- Feed-in tariffs
- energy purchase costs of PBS
- energy purchase costs of Formatwerk and
- energy costs within the energy community.

Economic results and optimal energy flows on a monthly basis can be seen in Figure 32 and Figure 33. The assessment of the economic vitality of this business model, involving energy exchange across corporate boundaries and even across different network operators, was satisfactorily conducted using the previously presented energy exchange platform. This evaluation served as the foundation for the planning activities related to the construction of PBS. Due to delivery and installation delays, this project was only implemented after the reporting period of Indugrid.

The exchange platform effectively facilitated the comprehensive evaluation of the economic robustness of the energy exchange business model, spanning across corporate boundaries and diverse network operators. This evaluation, in turn, played a pivotal role in shaping the strategic planning initiatives for the construction of FA. PBS. However, owing to unforeseen delays in delivery and installation, the project was executed post the Indugrid-project.

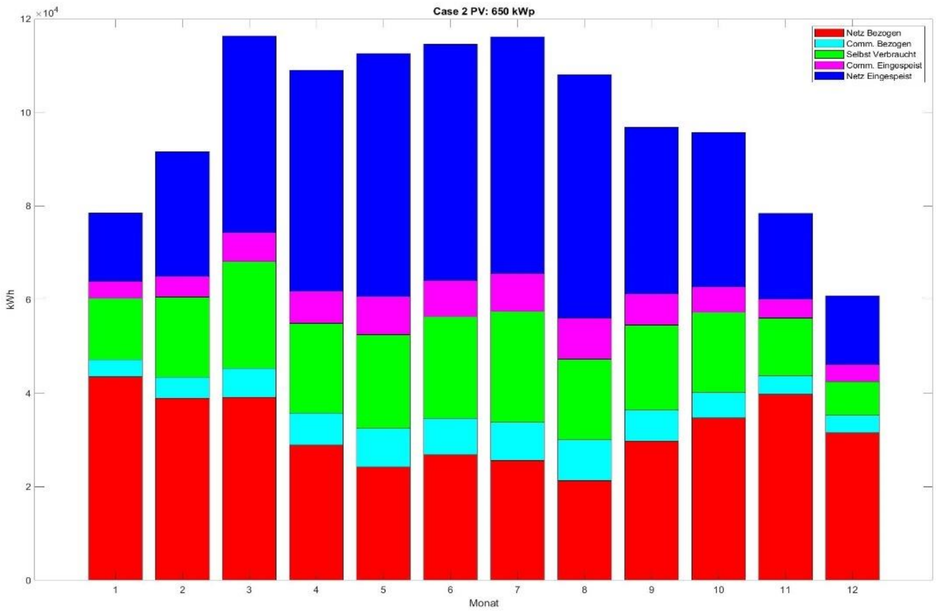

Figure 32: Optimal energy flows in a Citizen Energy community with increased PV-size (here: +650kWp). blue: Feed-in, purple: Exchanged Energy in the Community, Green: Self consumption, cyan: Power from Community, red: electricity purchase from Grid

	150 kWp		250 kWp		350 kWp		450 kWp	
	no EC	with EC	no EC	with EC	no EC	with EC	no EC	with EC
Format Werk	34 909 €	34 488 €	27 322 €	26 499 €	20 673 €	19 573 €	14 437 €	13 168 €
PBS	17 723 €	17 092 €	17 723 €	16 488 €	17 723 €	16 074 €	17 723 €	15 820 €

	550 kWp		650 kWp		750 kWp		850 kWp	
	no EC	with EC	no EC	with EC	no EC	with EC	no EC	with EC
Format Werk	8 403 €	7 013 €	2 472 €	997 €	-9 213 €	-10 795 €	-9 213 €	-11 814 €
PBS	17 723 €	15 638 €	17 723 €	15 511 €	17 723 €	15 349 €	17 723 €	15 284 €

	950 kWp		1050 kWp		1150 kWp	
	no EC	with EC	no EC	with EC	no EC	with EC
Format Werk	-14 991 €	-16 616 €	-20 742 €	-22 407 €	-26 470 €	-28 172 €
PBS	17 723 €	15 284 €	17 723 €	15 225 €	17 723 €	15 170 €

Figure 33: Variation of annual Costs for 2 participants of a Citizen's Energy community with variations of an additional PV-size from Formatwerk

3.3.4 Testbed Wels 3 – thermal energy exchange

Initial situation: The company headquarters of Rübig in Marchtrenk is a technology leader in thermal processing and uses different furnaces in their hardening processes, such as gas nitriding, vacuum hardening, case hardening, or plasma nitriding. Regular business hours are from 05:30 AM to 09:30 PM, operating in two shifts from Monday to Saturday, but several furnaces run 24 hours a day or more and operate on Sundays as well.

Waste heat utilization by Gerstl: Gerstl is in the direct neighborhood of Rübig, produces precast concrete parts, and requires thermal energy for the drying process. As part of this testbed, an investigation was conducted to determine whether waste heat from Rübig's cooling processes can be used in principle for concrete drying at Gerstl (Figure 34) and/or is suitable for heating purposes at Starlim/Sterner, which is also located in the neighborhood.

Technical boundaries
Seven hardening furnaces and an air compressor are linked to a hydraulic circuit with elevated temperature levels. The waste heat from these units is currently used to partially heat the administration building. Additionally, two 120 kW gas-fueled boilers are employed to support space heating and manage heating needs during peak power usage or extended furnace downtimes. If there is an excess of heat in the circuit, it is also directed to the rooftop cooling system. Furthermore, other externally cooled ovens are connected to the rooftop cooling system through two additional cooling circuits, divided into east and west circuits (Figure 35). Cooling circuits 1, 2 and 3 are filled with 50% glycol, the other measured circuits 4 and 5 with pure water.

Figure 34: Location of Companies Rübig und Gerstl and the considered thermal waste heat exchange network

The exhaust air system of the oil baths, used to cool products after the curing oven, is noteworthy due to its outlet temperature of approximately 40 - 45°C. However, the presence of oil and sulfur in the air makes it economically unfeasible to repurpose the heat for other uses. As a result, the following investigation for waste heat usage primarily focuses on assessing the surplus heat from the hydraulic circuits.

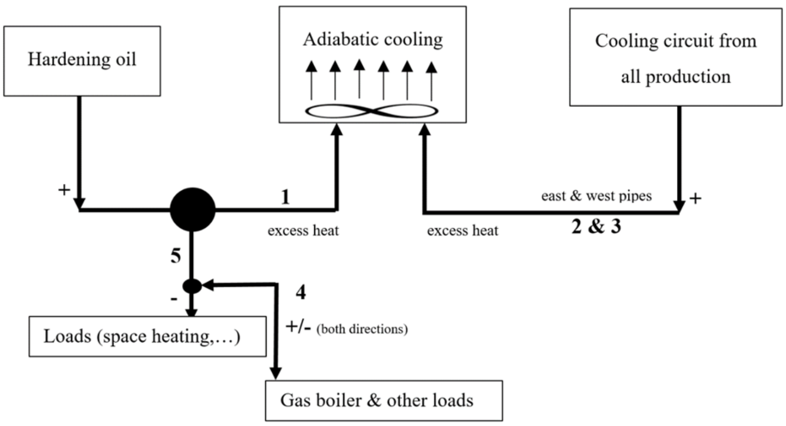

Figure 35: Hydraulic scheme of the usable excess heat circuits (1, 2 and 3) and other (4, 5)

For the examination of suitability measuring equipment on the relevant hydraulic cooling circuits have been installed. A total of five circuits were defined for power and flow measurements over different periods of time. These five measuring points are named according to their previously assigned designations:

- measuring point at "Primärkühlung Rücklauf Hartöl Rückkühlung"
- measuring point at "Primärkühlung Rücklauf RKW-B/D/2001/2013"
- measuring point at „Primärkühlung Vorlauf RKW-A/C/2011"
- measuring point at „Verbindungsleitung Kessel-WRG Rücklauf"
- measuring point at „Pumpenleitung WRG Vorlauf"

Figure 36 and Figure 37 show the relevant pipes in the installation room and in the basement. The entire measurement was carried out with three FLUXUS F601 portable flow meters and an ALMEMO 2890-9 V5 (Figure 38).

Figure 36: Circuits 1, 2 and 3 in the installation room

Figure 37: "Pumpenleitung WRG Vorlauf" (left) and "Verbindungsleitung Kessel-WRG Rücklauf" (right) in the basement

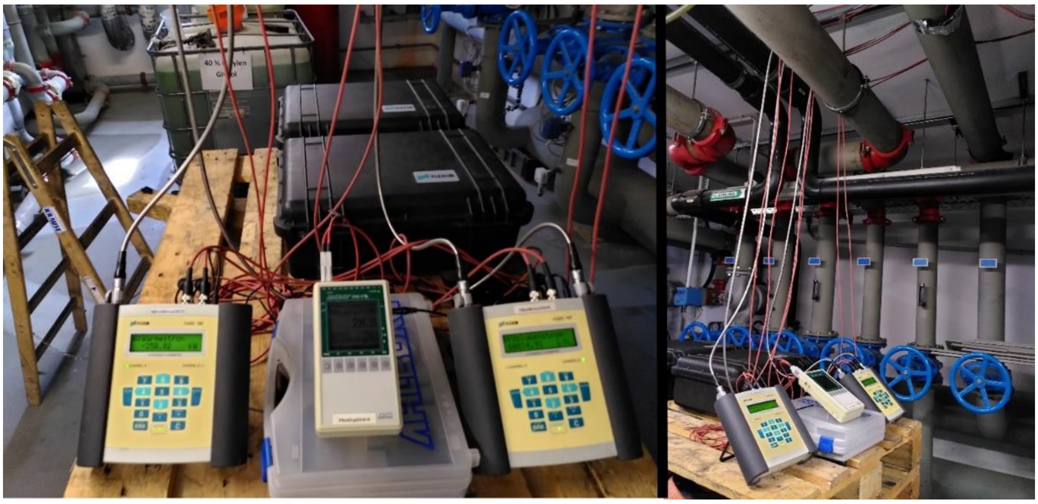

Figure 38: Measurement set-up for the circuits 1, 2 and 3

The initial findings show that the maximum useful temperature in circuit 1 can rise to forty to fifty°C in some cases. According to Rübig's technician, these peak values occur in the last half hour of the oven program when the product is cooled down. Circuits 2 and 3 have constant temperature levels of around 20 to max. 30 °C. The higher temperatures could be used directly for other processes, while the lower temperatures could be utilized indirectly by using heat pumps to raise them to the temperatures relevant for space heating.

The average output of the thermally available heat from circuits 1 and 2 is around 400 kW. With an industrial heat pump, this would be a good source to reuse for low temperature processes or space heating applications. The power peaks from circuit 1, with the higher temperature, are intermittent and only occur on a few days in winter.

The next steps have been the analysis of the surplus heat at the Rübig company and to evaluate and calculate the suitability and feasibility of its use for space (and process) heating for the Gerstl company. Figure 39 displays the analysis of the measurements and the potential thermal energy available. It is evident that the previously promising hardening oil circuit, with its significant temperature differential, only offers heating power intermittently during the autumn season. As the outside temperature decreases, more of the waste heat is already used for internal purposes (such as space heating, for example, through pendulum tube 5), leaving little potential for further utilization. However, the cooling circuits (2 and 3) consistently provide an output of approximately 400 kW.

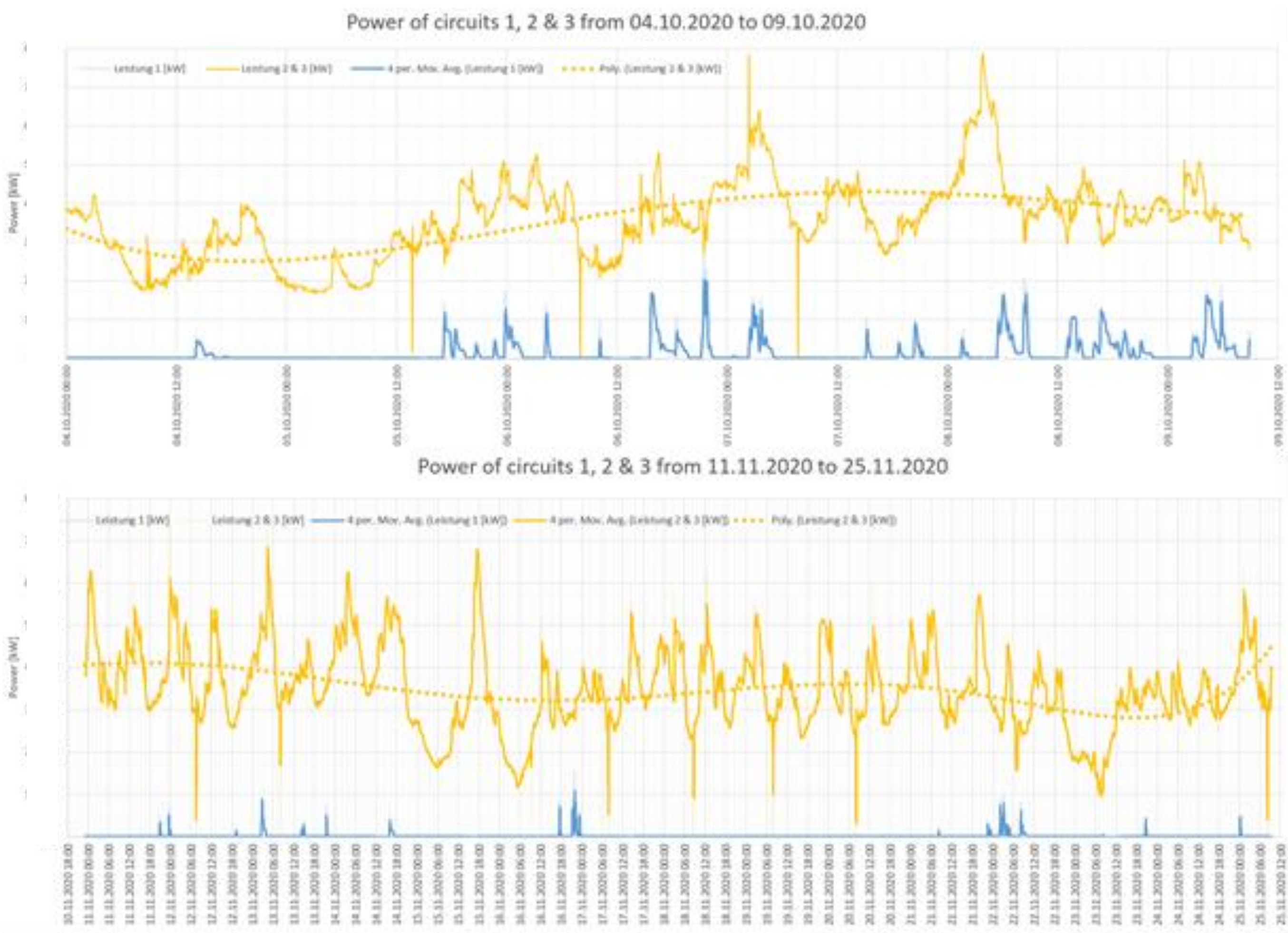

Figure 39: Thermal output of the hardening oil (blue line) with partially peaks of 40-50 °C and the cooling circuit of the other production (yellow) with a temperature level of usually 20-30 °C

In addition to the waste heat utilization, Rübig's internal energy consumption was also analyzed. The company's most relevant energy flows are gas and electricity, which can be seen in Figure 40. The figure clearly shows the weekly energy consumption (52 peaks a year), which results from the low energy demand at weekends. The production stop during the Christmas holidays can also be seen in the energy consumption. The high amount of reactive power is also striking, accounting for almost half of the total electrical output in some cases.

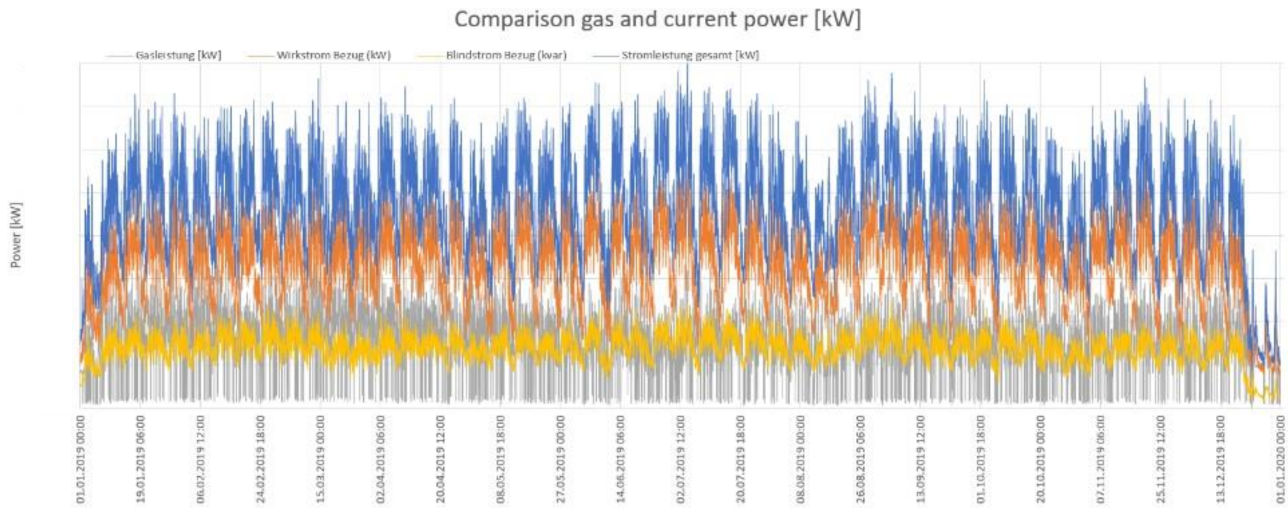

Figure 40: The energy flux (gas in grey, electricity in blue) of the company Rübig over the year 2019

Subsequently, some analyses were carried out to find a correlation between electricity, gas and the production mass in the annealing furnaces (Figure 41). The data integrity of the batch weights in this period is 95.48%. Unfortunately, there is no visible indication of a correlation that each spike in batch weight also increases energy consumption. Only the longer trajectories seem to be the same: the more material is processed, the higher the energy consumption over the average time. Another interesting finding is that there is a plateau of about 420 kWth during the production stop at the beginning of the year and some short low gas consumption values between 45 and 90 kWth (equivalent to 4-8 standard cubic metres of gas).

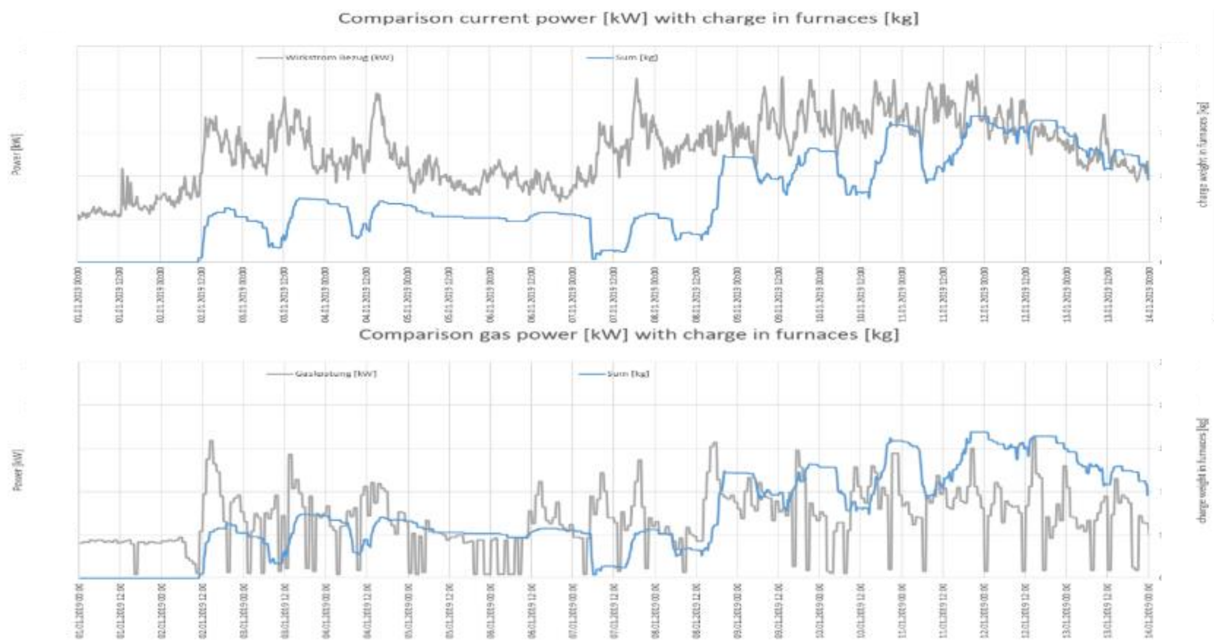

Figure 41: Electrical and gas power compared with the charge weight in the furnaces

Business case evaluation and findings

The findings indicate that cooling circuits 2 and 3 yield an approximate heat output of 400 kW. When paired with an industrial heat pump, this nearly constant heat source is capable of transferring waste heat at higher temperatures to nearby companies like Gerstl. A detailed examination of the thermal energy needs of neighboring enterprises, the feasible distance for a heating pipeline, and the resulting storage capacity for an industrial heat pump could offer initial estimates for investment and production costs, enabling the provision of thermal energy to other businesses. Gerstl must also consider this heat potential when designing their building to establish an exchange system with optimal efficiency.

The project proposal aimed to explore the technological viability of a heat exchanger in Wels. However, based on the thermal waste heat analysis results from Rübig company and the specific needs of the project partner Gerstl, which involved aiding the concrete drying process and preheating preliminary products, the establishment of a heat network between Rübig and Gerstl did not occur within the scope of this project.

The primary factor leading to the abandonment of the heat exchange collaboration was Gerstl's decision to avoid dependency on heat supply from Rübig. Concerns arose regarding the potential risk to Gerstl's heat provision should Rübig's production decrease. Consequently, Gerstl opted for an autonomous heat supply, planning to install a 250 kW gas boiler. The proposal for the new production facility was submitted within the project timeline, with expectations for its completion by 2025.

3.3.5 Testbed STIWA – thermal energy exchange

Due to the non-realization of the initially planned heat exchange concept in Wels (see previous chapter 3.3.4, an opportunity arose to include an additional application example from STIWA within the project scope. This expansion not only enriched the project's scope but also provided a valuable opportunity to explore a new application within the project.

A demonstration of an energy exchange was successfully implemented between two buildings of the company STIWA, utilizing an innovative methodology aimed at enhancing energy efficiency through the exchange of thermal energy. The fundamental concept involved utilizing the same connection pipe to deliver hot and cold media during different operational phases.

This new methodology encompasses several key procedures [14]. Initially, all energy processes involved were meticulously identified, classified, and modeled. Subsequently, a hydraulic system was defined independently of software, based on a graphical representation of energy flows. The solution was directly exported into a control software programmed using the GML (Graphic Motion Language) tool. This language enables the creation of SPS programs for the processes defined by PPR (Product Process-model Resources-model). This innovative approach has the potential to significantly optimize energy utilization within the company's operations but also in energy communities.

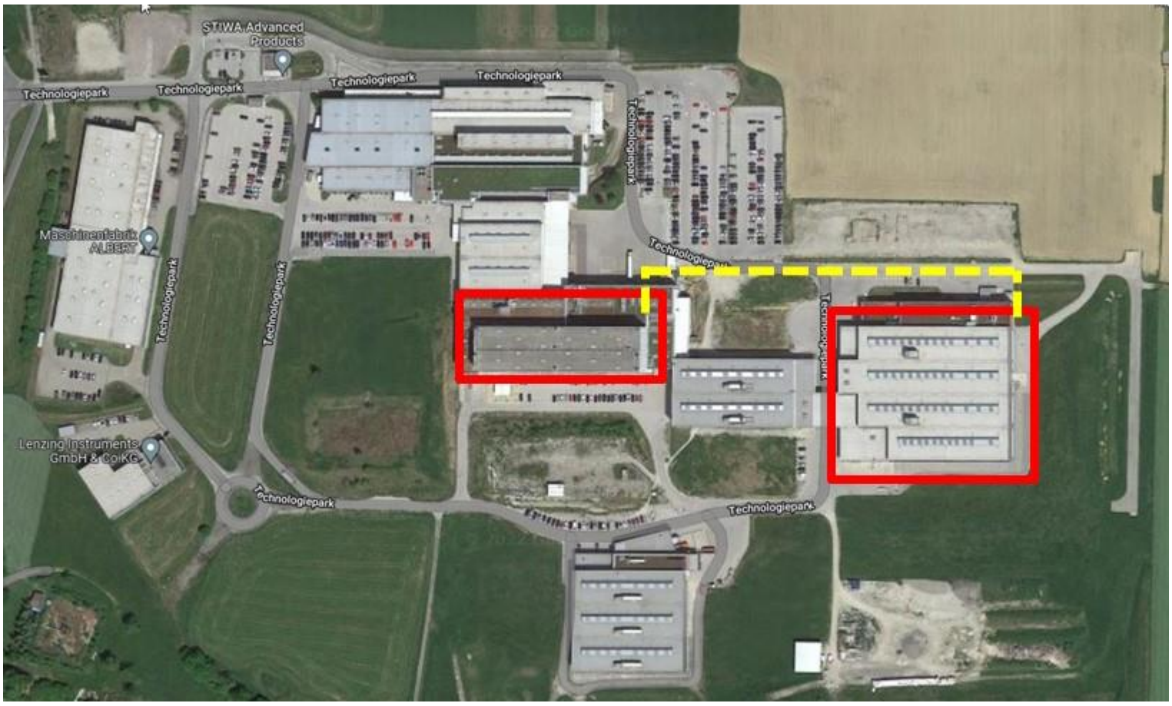

Figure 42: Situation of a thermal exchange (both hot and cold fluids) between two buildings

The main novelty of this development is the implementation of a heat and cooling fluid exchange system between for 2 participants. Figure 43 provides a schematical description of the winter and summer thermal exchange cases between the participants designated.

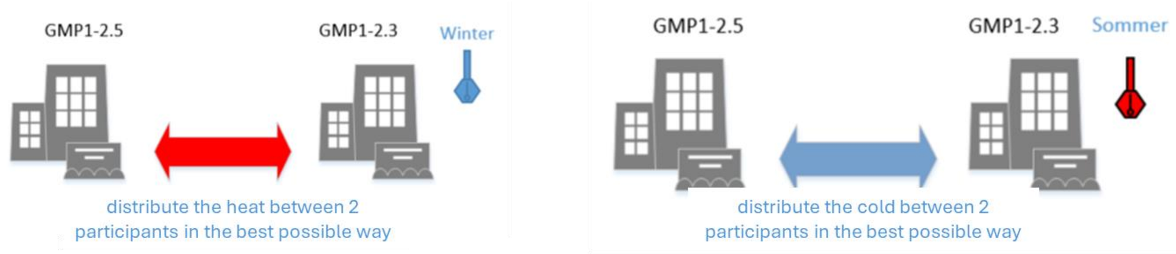

Figure 43: Energy flows in winter and summer operation between two participants

Initial Requirements of this test site have been:

- Supply of both participants with heat or cooling (support or complete supply) and vice versa.
- Reduction of operating hours of gas boilers, primary supply by heat pumps
- Reduction of CO2 emissions and surplus energy disposal
- Maintaining reliable energy supply to both participants (building and machine operation)
- Protection of buffer storage against discharge by energy transport necessary (heat pumps)

Once the requirements had been defined, the processes required to fulfil the requirements were designed. The aim of the process modelling was to present all the operating modes that the system can provide in a simple and understandable way. This can later serve as a basis for communication with the user or customer to decide which modes the system should really provide versus which processes are not necessary.

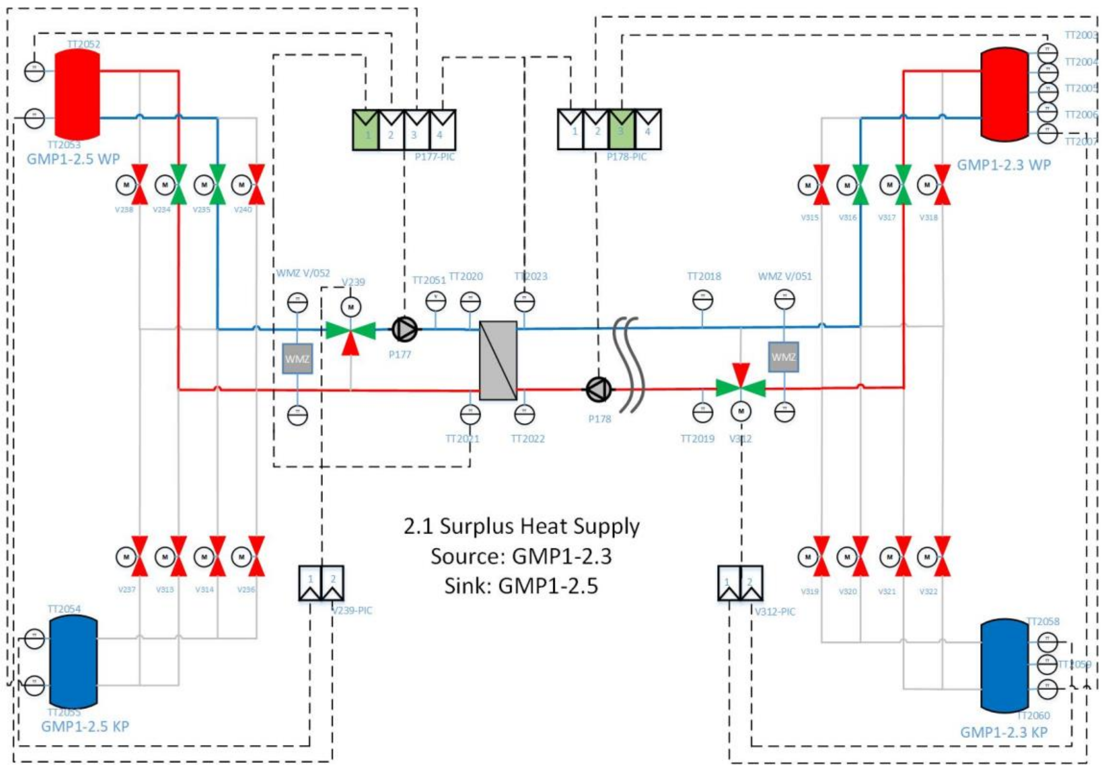

Figure 44: Hydraulic scheme of thermal heat/cold exchange

In this project, the method of energy flow diagrams was used to model processes. A total of 14 different operating modes were identified as part of the realization of the heat/cold exchange (Figure 46).

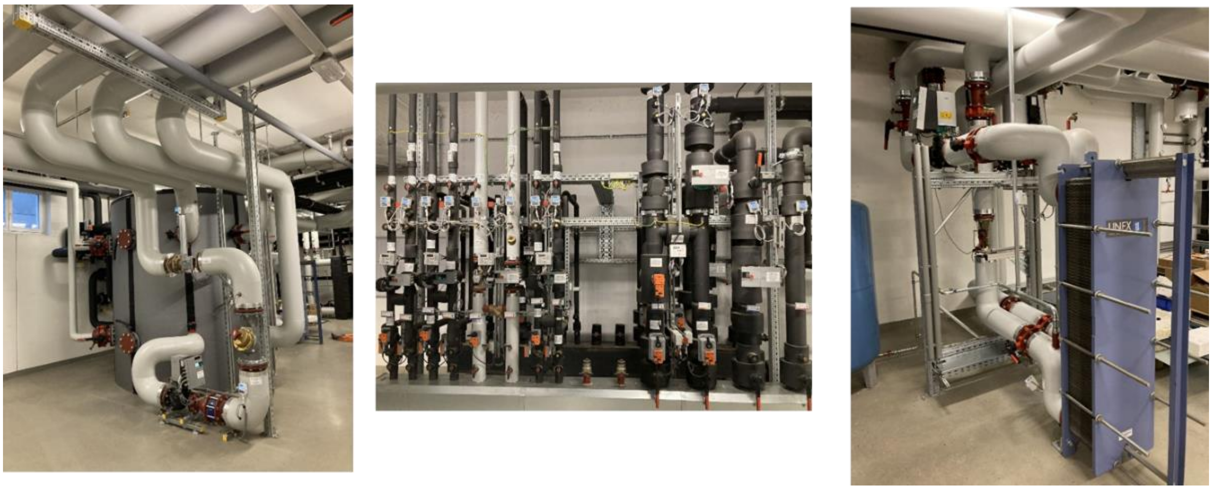

Figure 45: Visual impressions of the implementation of the process

The solution proposed considers the development of a hydraulic system and its control based on an own developed software implementation:

- Hydraulic system: The envisioned energy transport system is linked to the hydraulic systems of both participants through heat and cooling water storages (Figure 44). One of the buildings is equipped with heat pumps that supply thermal energy for the building, along with compressors featuring waste heat recovery systems. Meanwhile, the other building houses a gas boiler and cooling machines, also integrated with waste heat recovery systems. The thermal energy generated is utilized for heating and cooling the buildings, as well as providing process cooling for production machines. Furthermore, waste heat is efficiently managed using free cooling devices in both buildings. This integrated approach demonstrates a comprehensive strategy for optimizing energy utilization and waste heat recovery within the facilities.

- Control unit of the hydraulic system: It contains an overview of all the documents required for each process. Another important document in the context of resource modelling is the Failure Mode and Effects Analysis (FMEA). Processes carried out: Heat and cooling energy transport from participant 1 to participant 2 and vice versa (excess energy supply or sole energy supply)

- Software: Converting a system based on rule description depicted in flow charts into a computer-readable language. Utilization of the graphical programming tool GML (Graphic Motion Language) for creating SPS programs based on the processes defined by PPR (Product Process-model Resources-model). The workflow of these programs encompasses the following stages: (1) Trigger, (2) Decision tree, (3) Action, and (4) Awaiting a new trigger. This approach facilitates the seamless translation of complex system logic into executable computer programs, enhancing (Figure 47)

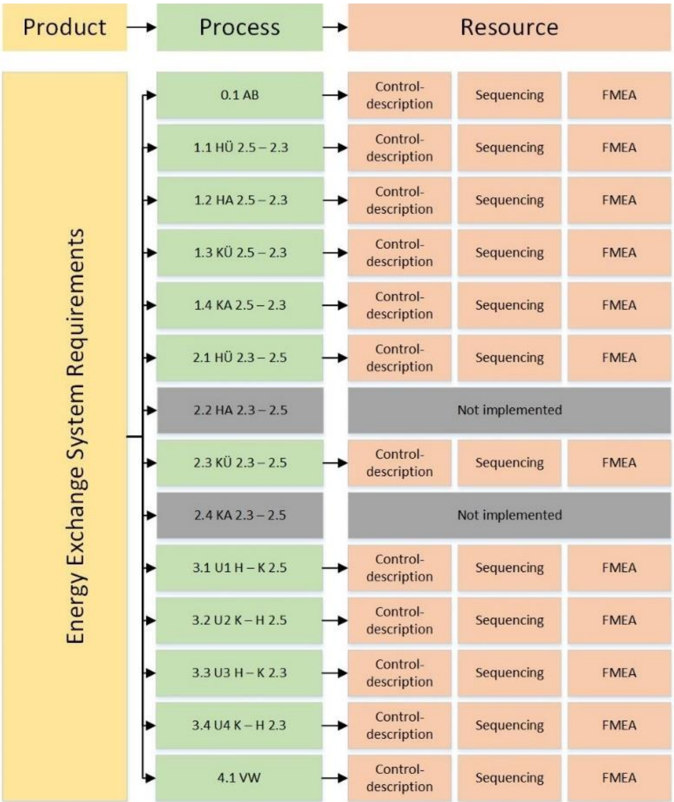

Figure 46:List of possible operational modes for thermal exchange

Findings of this use case

The energy transport system, which was commissioned in March 2022, encountered initial start-up challenges that needed to be addressed. These included:

- A pump unit experienced mechanical issues, leading to a delayed commissioning in May 2022
- Significant power peaks, exceeding the commission limits, were observed due to cold water "drops" in the energy transport system.
- In the first phase, the prioritized processes focused on heat exchange to reduce the required gas. Consequently, during the summer, cooling energy exchange was not operational, and as a result of no heat requirement in both buildings, significant energy transport between the two buildings was not feasible as of September 2022.

These challenges necessitated a rework of the software and process control, resulting in regular heat/cold transport operations in autumn 2022. Subsequently, from this phase onward, the anticipated energy exchange between the two participants was operational (see Figure 48, Figure 49).

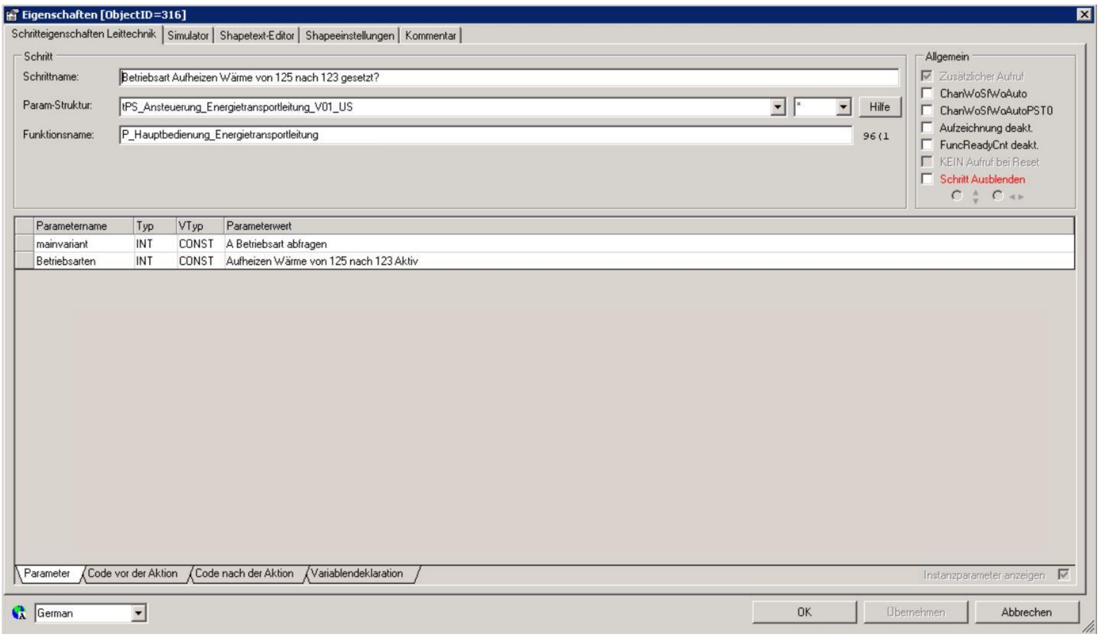

Figure 47: Software-window of the control solution for thermal energy exchange

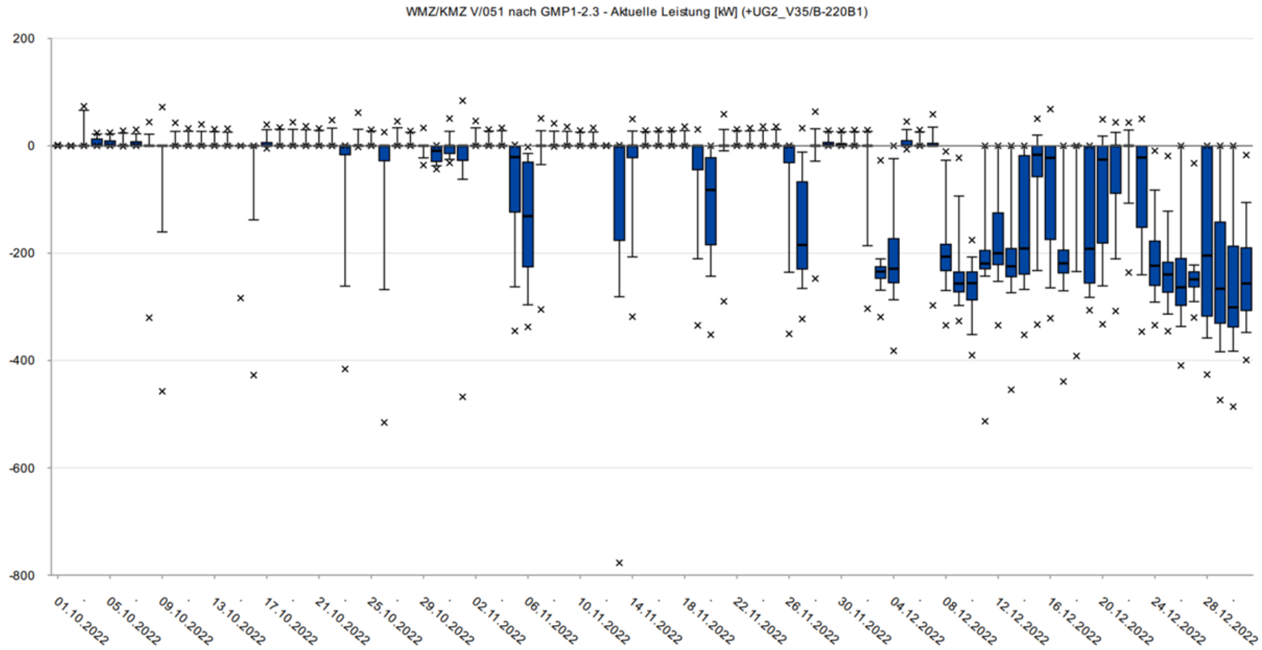

Figure 48: Performance trend from 1.10.2022 to 31.12.2022

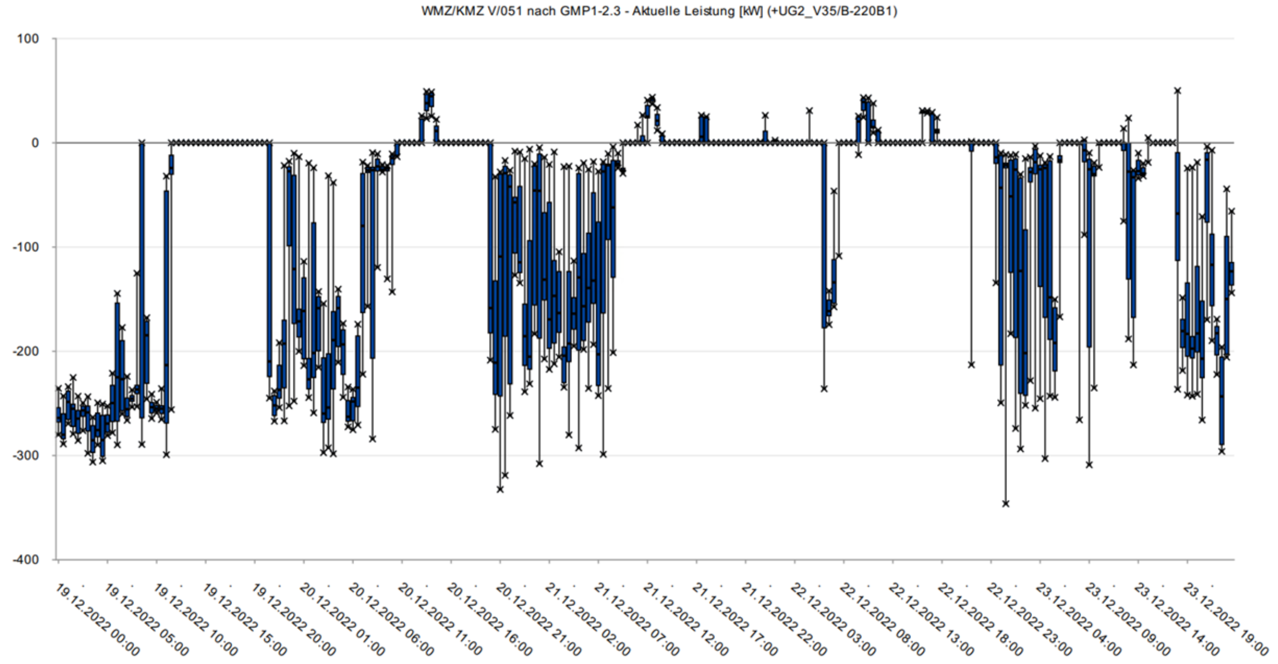

Figure 49: Performance trend from 29.12.2022 to 23.1.2023

3.3.6 Testbed Hagenberg 2

The municipality of Hagenberg initiated the planning of an energy community in cooperation with different companies, public institutions, and private households. Figure 50 depicts the most relevant participants of the energy community in Hagenberg:

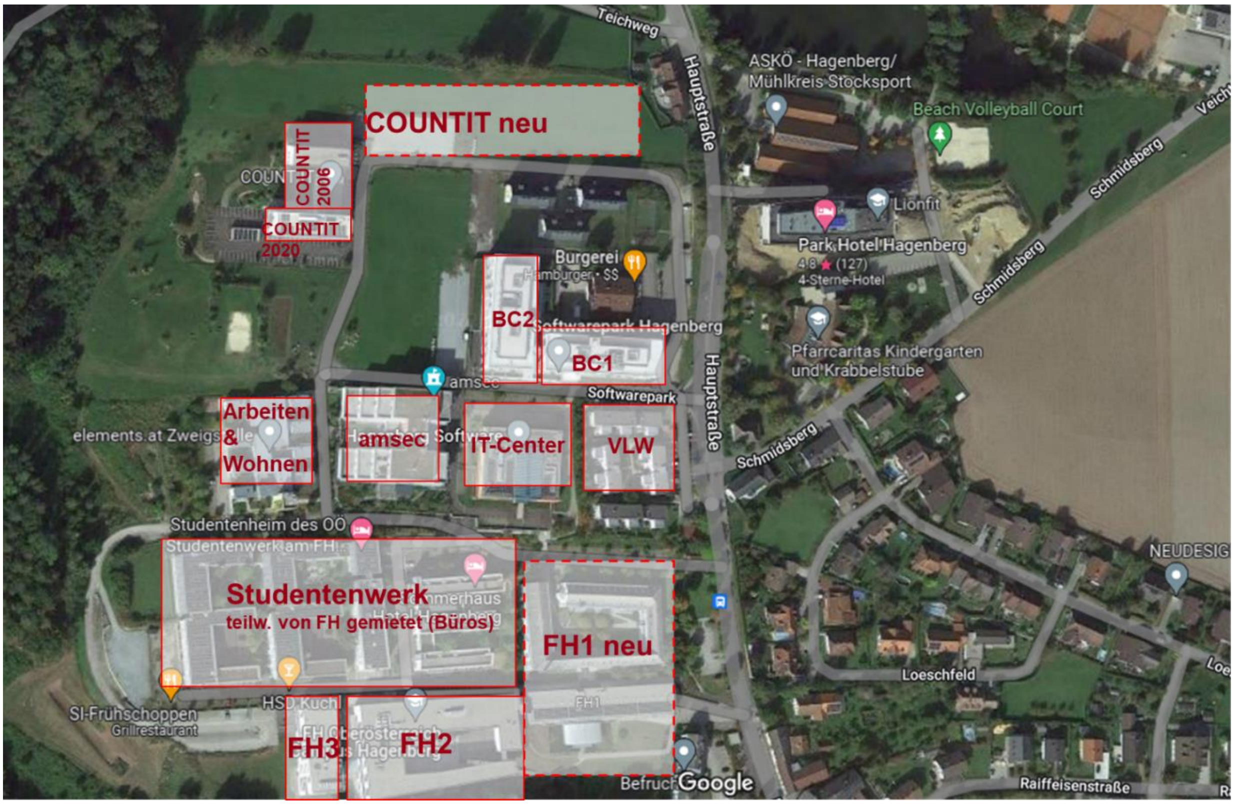

Figure 50:Relevant participants of the energy community

Within the energy community, electricity and heat are exchanged. Thanks to a combined heat and power (CPH) system, not only heat (55% of the power) is generated, but also a share of the electricity (25% of the power). With the support of different photovoltaic plants, the energy community will serve itself. The power of the combined heat and power system cannot be dynamically regulated, and it operates only under an on/off condition. For this reason, the combined heat and power system will be supported by a woodchips boiler by heating generation. The whole system is equipped with a heating reservoir of 800 kWh.

The goal of the analysis carried out here is the dimensioning of the CHP system. The installation of PV plants was already established at the time of this study: most of them were already set up and those not yet installed, had passed the planning phase.
Table 2 classifies the participants of the attending community according to the kind of use, surface, current heating system, PV availability, electricity and heating loads, and their participation in the district heating and electricity community. Table 3 summarizes the prices of the different energy sources.
Some extra assumptions for the analysis of this energy community are:

- Gas and oil consumption 100% replaced by the application CHP pellets and PV plants (only participants environment Software Park).
- All facilities with unknown heating systems are considered gas heating.
- Each participant has electricity and heat loads (only participants surrounding Software Park)
- Municipal office, music hall, elementary school and kindergarten are heated with heat pumps.
- Load profiles for offices modelled after mapping of Stiwa's load data.
- Currently no cooling considered.
- COP air source heat pumps = 3.5

Table 2: Summary of characteristics of the participants

	Participant	Type	Surface	Heating technology	PV Capacity	Heating Consumption	Electricity Consumption
			m²		kWp	kWh	kWh
1	COUNTIT_2006 (SWP_49a)	Office	1500	Pellets	0	224661	662751
2	COUNTIT_2020 (SWP_49)	Office	2500	LW-WP	0	374435	1104585
3	COUNTIT_neu	Office	13000	-	0	1947061	5743840
4	BC1 (SWP_32)	Office	4500	LW-WP	0	673983	1988252
5	BC2 (SWP_34)	Office	4500	LW-WP	0	673983	1988252
6	VLW (SWP_31f)	Flats	1500	-	0	210000	75000
7	amsec	Office	6500	Waste heat+WP	0	973531	2871920
8	IT-Center	Office	2700	Gas	0	404390	1192951
9	Arbeiten u. Wohnen (SWP_39)	Office + Flats	706	Gas	0	105740	311935
10	Arbeiten u. Wohnen (SWP_39)	Office + Flats	1700	Gas	0	238000	85000
11	Studentenwerk	Flats	16000	Oil	182	2240000	800000
12	FH1 neu	Office	18000	Gas	0	2695931	7953010
13	FH2	Office	6000	Gas	0	898644	2651003
14	FH3	Büro	3000	Gas	0	449322	1325502
15	ASZ			-	19.74	1626	2997
16	Gemeindeamt	Office	160	-	0	23964	41201
17	Bauhof			Gas	0	2020171	4940
18	Musikheim			-	0	80494	7476
19	Feuerwehr			-	0	7452	13732
20	Volksschule			Gas	11.28	30112	2797
21	Kindergarten			Gas	0	165477	22200
22	Sporthalle			Pellts+Gas	9.87	9310	17156
23	PV	-		-	171.94	0	0

Table 3: Summary of considered prices

Energy source	Costs
Heat CHP	10.00 Cent €/kWh
Grid sourced electricity	26.70 Cent €/kWh
Grid fed electricity	10.00 Cent €/kWh
EC Purchased electricity	13.00 Cent €/kWh
EC fed-in electricity	11.50 Cent €/kWh
Gas	15.50 Cent €/kWh
Heating oil	13.50 Cent €/kWh

The analysis of the EC comprises two categories of data. Firstly, all energy flows between all participants of the EC are considered with a 15-minutes time resolution for a whole year.

- Self-consumption.
- Energy drawn from public networks.
- Energy fed into public networks.
- Energy exchange with the energy community.

Secondly, and based on the previous analysis, economical aspects of the exchanged energy are also considered:

- Annual cost of each participant in the now situation.
- Annual costs of each participant in the energy community.

Figure 51 shows the structure of heating and electricity grids:

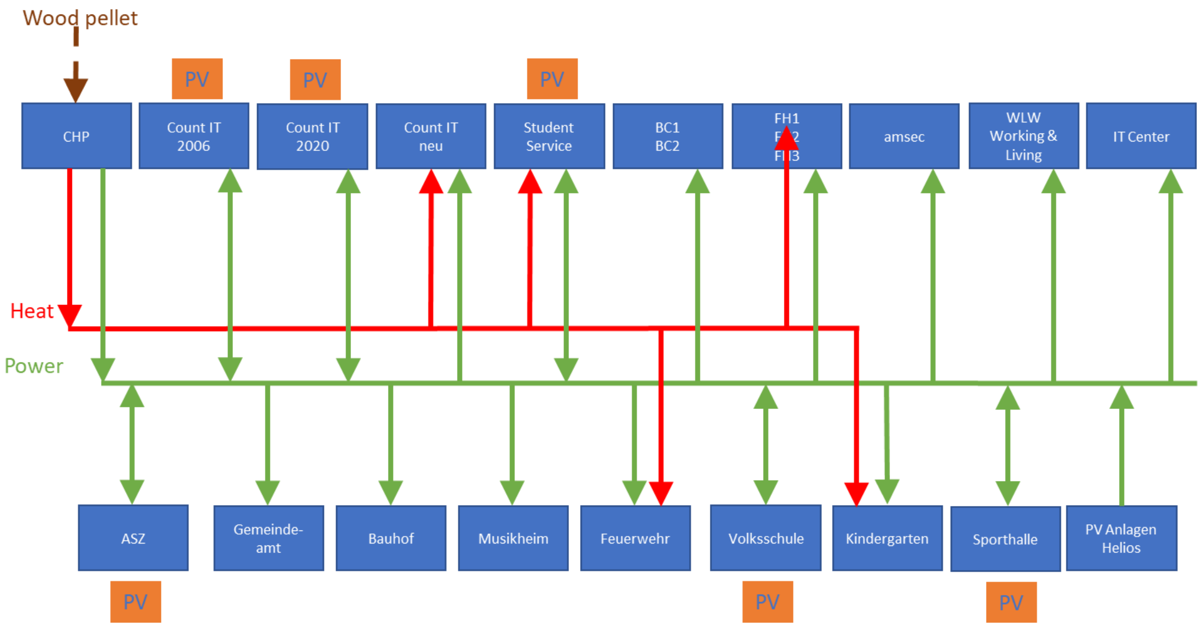

Figure 51: Structure of the EC Hagenberg used to model and optimize energy flows and costs

Business case evaluation and findings

Based on the previous data of demand and resources, costs, and structure of the EC, the previously mentioned energy flows, different powers of the combined heat and power system were analyzed. Each analysis consists of an optimization problem. Details about the optimization process were presented in previous reports of this project.
In this section are reported the results derived from the analyses. Table 4 summarizes the results obtained with the different powers of the CHP system

Table 4: Operative results of the CHP und Woodchips systems

Power CHP	Heat CHP	Woodchips	Electricity consumption CHP	Operative hours CHP	Operative Hours Woodchip
kW	kWh	kWh	kWh		
200	333 190	1 176 797	151230	3029	3621
150	261 071	1 230 333	118479	3164	3691
100	306 707	1 009 103	138983	5576	6200
75	243 550	1 159 969	110325	5904	4268

Further and more detailed information can be found in the appendix in Chapter 6.1
For the analysis of this case the following requested aspects were considered:

- Economic boundary conditions included the constraints imposed by the Austrian law of Renewable Energies (EAG- Erneuerbaren Ausbau-Gesetz). The main point here has to do with the limitations imposed by the law on network operators: they are not allowed to charge more than 5 cent €/kWh for electricity transferred inside of the energy community.

- The modelling system was extended to optimize the size of components. At the present case was optimized the power of the CHP of this EC.

- The current EC is composed of prosumers and consumers. To increase the own consumption of the energy produced in the energy community, some consumers were added. This increases the autarky of the EC and reduces the operative costs of all participants.

- Business models seem to be quite restricted because of the EAG. The aim of the law is focused on the amortization of investments from private households and medium and small companies. Furthermore, ECs in Austria must be managed by nonprofit-associations. In the present case, the EC will be operated by an association promoted by the municipality.

3.4 Sozio-economic impact

3.4.1 Stakeholder - Analysis

Beside other activities, the project InduGrid also aimed to understand regional targets and stakeholder needs, to determine the public value of industrial energy communities and the impact of the implementation. The tool SAMBA was created by the Energieinstitut for qualitative socio-technical assessments to reflect the generalized views of different people, groups of people or institutions. It identifies potential obstacles and views to be able to take appropriate measures tackling the challenges. Furthermore, the involvement of relevant stakeholders is advantageous for decision-making, can add information, save important resources and support targeted measures for active stakeholder involvement.

In the process of the analysis, the relevant stakeholders are identified and structured in six different groups (Administration, Politics, Associations & NGOs, Economic players, Press & media, Civil society). Afterwards stakeholder evaluation is conducted by applying a standardized questionnaire. Participants in process of stakeholder evaluation are asked to estimate the influence (power to change the direction of the project) and importance (active or passive interest on the project) as well as the general attitude towards the project of each single stakeholder according to their own experience and opinion. The different results of all participants are used to determine an average value for each of the listed stakeholders.

The identification process of stakeholders that are relevant to the project delivered a list of in total of 111 different stakeholders. While in total ten members of the project consortium checked the list of stakeholders and gave feedback, in the process of stakeholder evaluation, 15 persons from the consortium partners contributed with their individual evaluations which are afterwards summed up to an overall result of the analysis (see Figure 52 and Figure 53).

- Most of the stakeholders are expected to have a “neutral” or “positive” attitude on energy communities. However, there are many stakeholders, implying the need to manage these in case of implementation and to guarantee the support of those expected to be supporters.

- Four stakeholders, belonging to the same type of business background and role, may have an ambivalent attitude what means that they are maybe asking for background information or focused on possible critical points of the project. This does not mean that they are negative and direct problems concerning the implementation of the energy communities are expected. However, the respondents do not regard these four stakeholders as crucial for the project and thus attribute low influence and importance.

- No stakeholders or stakeholder groups are expected to be “opponents” and so no direct problems, or resistance can be addressed.

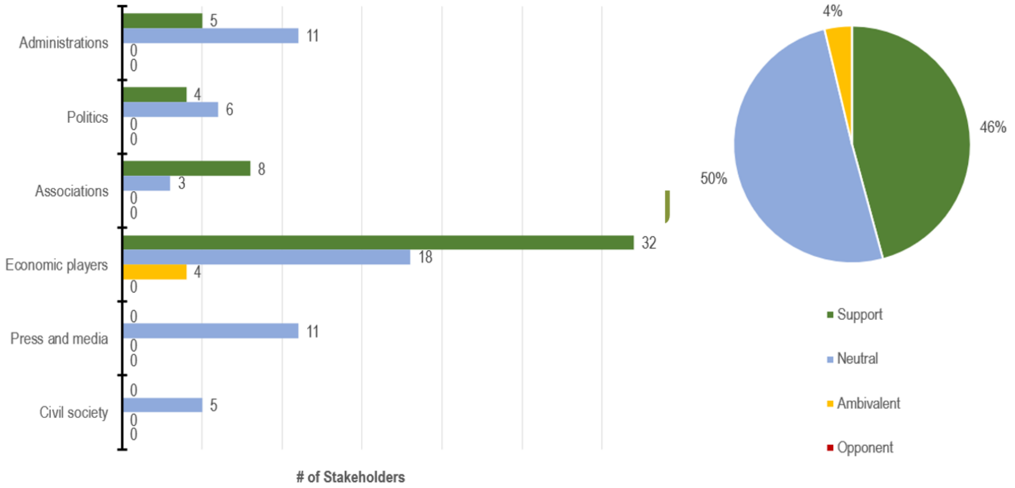

Figure 52: Stakeholder analysis: General attitude towards (renewable) energy communities

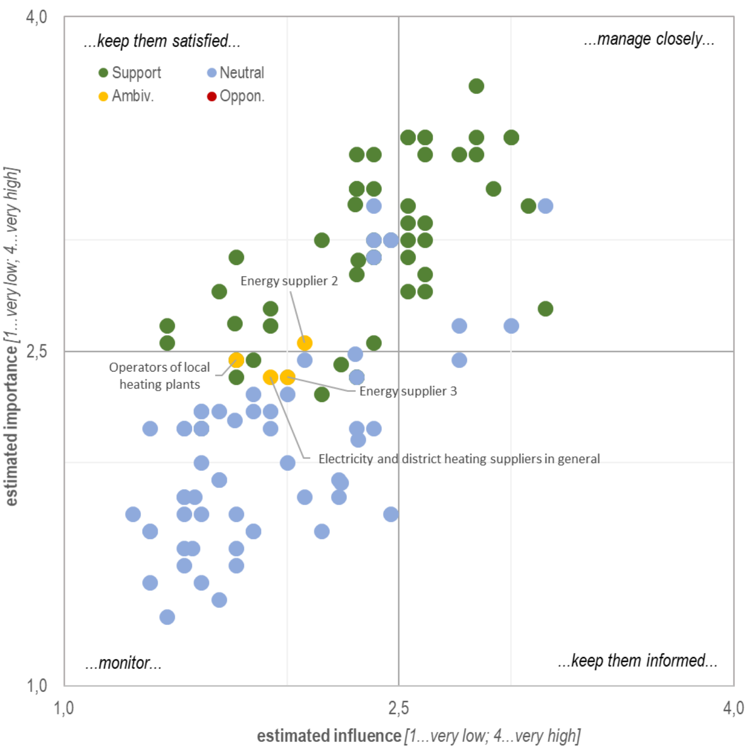

Figure 53: Stakeholder analysis: Effects and interest in (renewable) energy communities

3.4.2 Macroeconomic effects / waste heat utilization Ennshafen

The socio-economic assessment focuses on the macroeconomic contribution that is generated by the implementation of the testbeds' concepts derived in the InduGrid project by assessing the additional gross regional product (GRP), consumption (of private households), investments (of companies), net exports (exports - imports), and additional employees. The assessment is conducted with the macroeconomic tool MOVE2 that was developed at the Energieinstitut. The current simulations are based on the upscaled results of the techno-economic analyses of the testbed Ennshafen.

The simulation of the effects of an inter-company low-temperature waste heat utilization via heat pumps for space heating within the framework of InduGrid's testbed Ennshafen concept displays a positive economic benefit in the form of an increase in GRP and employment within the period 2020-2030. The simulation displays the effects that would occur if the estimated suitable Upper Austrian waste heat potential (13.6 GWh/a) would be utilized in the same way as in the Ennshafen testbed, i.e. install the same system at the same time.

The positive macroeconomic developments are mainly based on:

a) additional investment impulses in the first year (2020) due to the implementation of the heat pump and corresponding components as well as the engineering services.

b) positive effects on the trade balance (net exports) due to the decline in imports of natural gas for heat production due to the utilization of waste heat during the period 2020-2030, which exceeds over time the value-added outflows of the investments in 2020.

c) multiple round effects (on private consumption) from the previous items a) and b).

Compared to a situation without an inter-company low-temperature waste heat utilization via heat pumps for space heating, analysis shows an increase of GRP by approx. € 8.0 million in 2020 and by € 2.4 million in 2030. This corresponds to an average annual increase in GRP in Upper Austria of approx. € 3.1 million over the entire period from 2020 to 2030. Average annual increase in employment in Upper Austria is approx. 50 full-time employees over the entire period from 2020 to 2030.

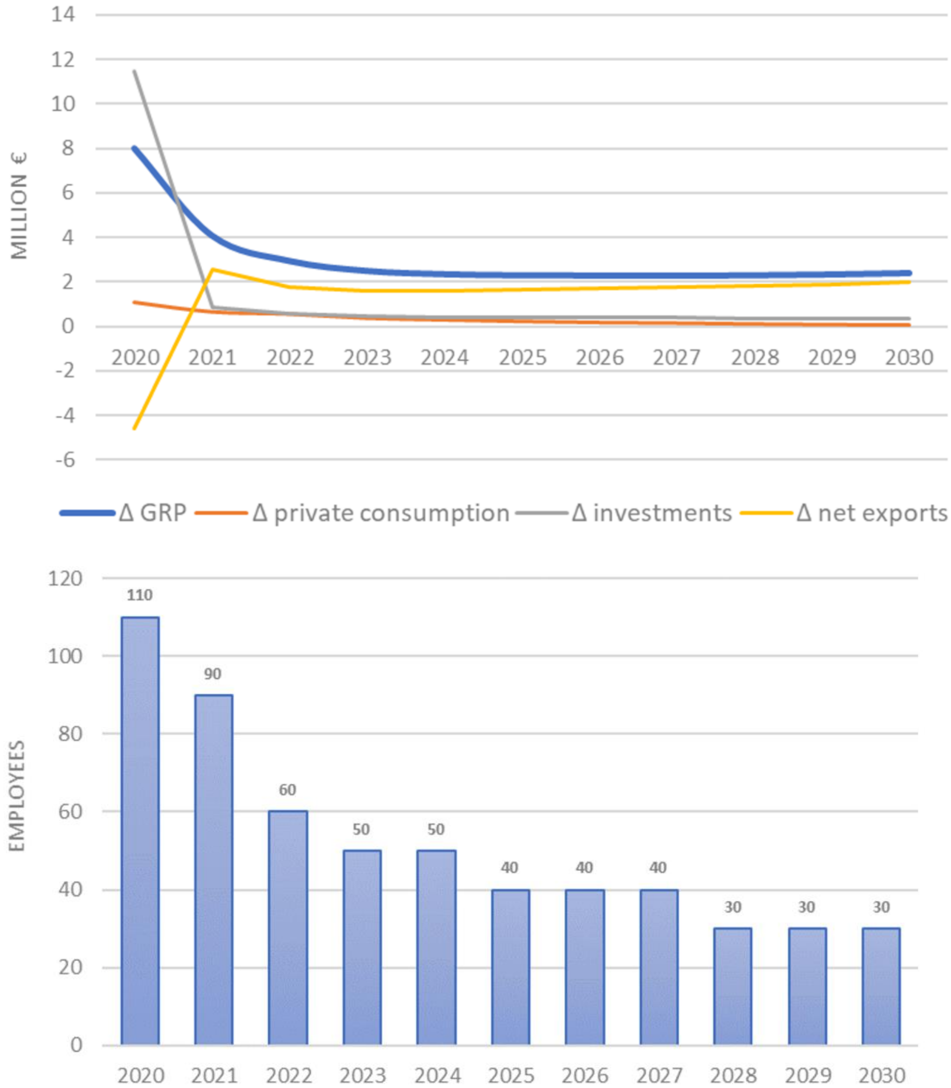

Figure 54: Results of the simulation analysis - GRP, consumption, investment, net exports, employment; additional effects. Source: Own calculations with the simulation model MOVE2

3.5 Dissemination of project results

3.5.1 Living Lab

The targeted development of energy communities requires the engagement of stakeholders involved. To support the development of the framework and design of a setup, desk research on successful cooperations for energy exchange between companies has been performed. This resulted in an extensive collection of cooperations worldwide. To integrate the results into the living lab process and support the stakeholders in the setup of their own cooperations, the best practices have been brought into a poster format. Overall, seven posters have been prepared giving an overview of different types of energy exchange between companies:

- Direct thermal connection
- Industrial thermal microgrid
- District heating supply
- Electric microgrid
- Virtual power plants
- Peer-to-peer electricity trading and
- Energy communities.

The posters should provide the relevant knowledge about possible cooperation types with minimal need for detailed explanation. Since the relevant stakeholders come from different fields and professions, the language used in the posters had to be kept simple and adapted to their needs. The information provided included a brief overview of the technological solution along with the motivation, intention and involved stakeholders.
The posters (example in Figure 55) have been presented to the companies at a workshop organized in Linz on September 16, 2019, in an initial “brainwalk” where the stakeholders indicated the relevance of the poster topics for setting up their own energy community.

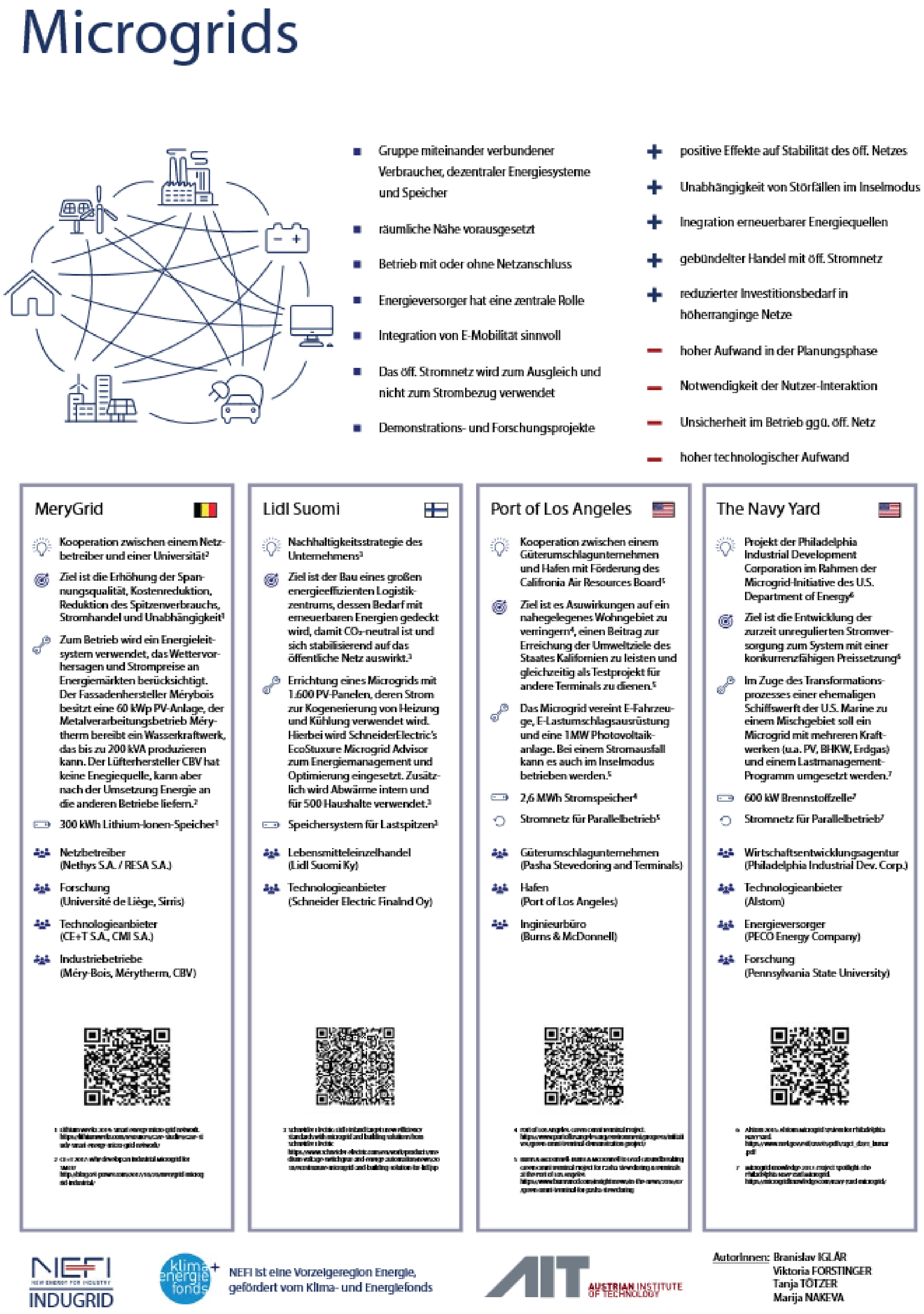

Figure 55: Example of a poster for the "brainwalk"

3.5.2 Fact sheets

As part of the preparation of factsheets for potential participants in energy communities, a special design was created. This is based on the idea of presenting the essential content in a condensed form on a folder (landscape format with a third fold). Four different drafts or variants were created, which present the key facts in a simplified way and thus contribute to reducing complexity. The main components of the factsheet are:

- The comprehensible preparation and visualization of the data on energy communities in a combination of text, diagrams and symbols.

- The presentation of different test cases of a renewable energy community, differentiated into participants with and without their own PV system, as well as the resulting savings for the 6 test cases shown.

- General information on what renewable energy communities are, what benefits they offer to consumers and producers, how many costs and charges to expect and what steps need to be taken towards setting up an energy community.

- A schematic diagram of a test case with an energy community.

- The presentation of a timetable until implementation as well as a further time forecast.

The design of the factsheet aims at a better illustration and communication of the functioning of energy communities as well as the different effects, advantages and disadvantages for different sized participants (e.g. hospital, school, industry, private household) of an energy community. The contents and the design of two shortlisted variants were coordinated with Wels Strom and finally adapted after several feedback loops. Figure 56 shows the final design of the factsheet.

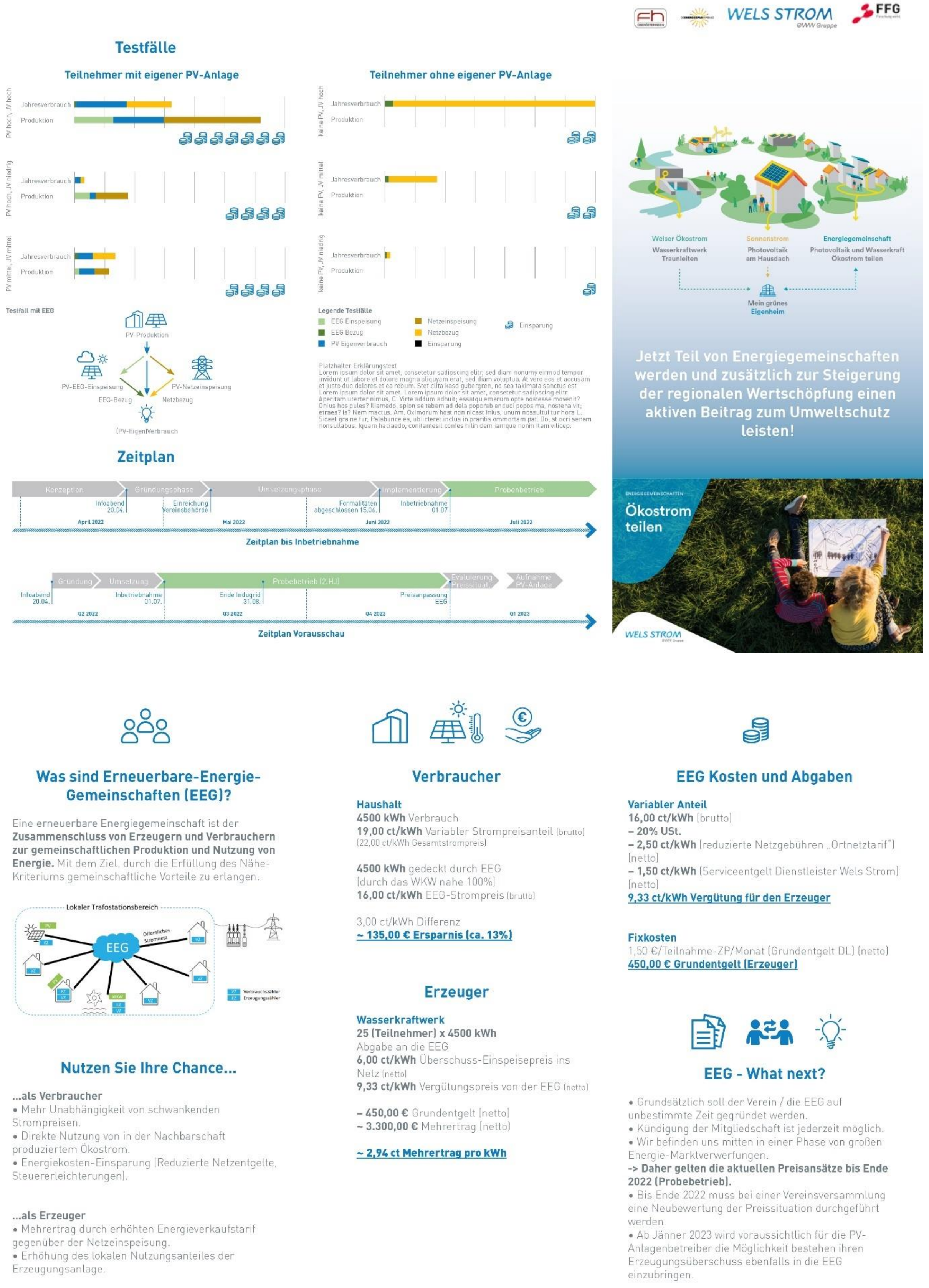

Figure 56: Front and back of the three-part fact sheet

3.5.3 Publication and Presentations

Presentation of “InduGrid Testbed Ennshafen” in course of a workshop on energy cooperation in the course of “Forum Econogy 2019” (invitees only) – Project partner EI-JKU

Gerald Steinmaurer, Christoph Schaffer, Shievam Kashyap, Tobias Hofer, „Energy Communities: Utilization of the Energy Exchange Potential in Industry”, Mission Innovation Austria Week 2019, Poster Presentation, 09 - 10 May 2019

Marie Holzleitner & Simon Moser, “Energy efficiency in the district heating sector – an analysis of the Renewable Energy Directive regarding alternative feed-in options”, ECEEE Summer Study 2019, 3–8 June 2019

Marie Holzleitner, Simon Moser, Stefan Puschnigg, Evaluation of the impact of the new Renewable Energy Directive 2018/2001 on third-party access to district heating networks to enforce the feed-in of industrial waste heat”, Utilities Policy, Volume 66, October 2020, 101088

Marie Holzleitner, Simon Moser, „“Rechtliche Möglichkeiten für die Einspeisung von Abwärme in ein bestehendes Fernwärmenetz – eine Analyse der Neuerungen durch das „Clean Energy Package“, ZTR 02/2020.

Gerald Steinmaurer; “An optimization approach to control the energy flows in renewable energy communities”, 13th Conference on Solar Energy for Building and Industry (EuroSun-ISES), Athens, 2020.

Christiane Egger, " Industrial Efficiency 2020 – Decarbonise Industry!", eceee conference, 12/2019 (paper), 09/2020 (oral presentation)

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Fernando Carreras, Peter Zellinger, Johann Brandmayr, Gerald Steinmaurer: „Heat Exchange in Industrial Microgrids", Poster contribution, Second scientific conference of the NEFI Innovation Network, October 13-14, 2022 in Linz, Austria

Information about the possibilities of energy communities was provided in a series of presentations and the topic was included in a range of communication activities, e.g. at the following events:

- Forum Econogy 2019
- Info round-table “energy communities” (10 Dec. 2019)
- CTC Energy Update event (27 Jan. 2020)
- CTC Energietechnologie Innovationsworkshop (21 April 2020)
- MIA online event "Energy Communities" (17 June 2020
- Forum Alpbach, NEFI breakout session (27 Aug.2021)
- Smart E-Mobility Conference (24 June 2021)
- NEFI conference (6-7 May 2021)
- Innovative Finanzierungslösungen für Energieinvestitionen in Unternehmen (17 March 2021)
- Größere PV-Anlagen finanzieren und betreiben (4 Feb. 2021, 4 May 2021)
- NEFI OC Workshop "Innovationstalk Energiespeicher in der Industrie" (3 Nov. 2020, online)
- Info-Roundtable Energiegemeinschaften (14 Oct. 2020)
- Innovationsforum betriebliche Energiewende (15 Oct 2020)
- Vorzeigeregion Event "Innovationen Made in Austria" (29 Sept. 2020, Linz)
- OÖ. ESV, Tagung Die neuen Energiegemeinschaften", 20. April 2021
- Event "Forschung #Industrienah: "Gemeinschaft. Macht. Energie" (FH Wels, 20 Sept. 2021)
- Seminar "Energy efficiency for industry" (24 May 2022, Linz)
- Innovation forum "Renewable heat" (1 June 2022, Linz)
- NEFI Talk "Flexibilisation and energy exchange" (6 July 2022, online event)
- Info-event and seminar "Energy communities" (19 July 2022 and 9 June 2022, Linz)
- Seminar “E-mobility for companies” (6 Oct. 2022, Linz) which put a focus on load management, PV integrated solutions
- Seminar “Energy communities” (11 Oct. 2022, Linz) with a focus on grid integration and information on different energy communities schemes
- NEFI Conference (13-14 Oct. 2022, Linz): Indugrid Poster presentation, platform for networking and exchange
- Seminar “Energy communities in practice” (18 Oct. 2022, Linz) with a focus on detailed information on energy communities (step to step advice for establishing) and highlighting the NEFI E.Factory tool for schools
- Seminar “E-mobility for apartment blocks” (3 Nov. 2022, Linz) which put a focus on load management, PV integrated solutions for multi-family buildings and companies
- Seminar “PV, E-mobility, storage & Co” (9 Nov. 2022, Linz) highlighting solutions for the integration of PV, storage and e-mobility
- Conference “Saving energy costs in companies and municipalities” (22 Nov. 2022, Linz) including a presentation on electricity load management and energy exchange
- Seminar “Energy flexibility for companies” (19 Jan. 2023, Linz): presentation on energy exchange in companies including Indugrid test hub examples

3.5.4 International Clean Energy Challenge (22-26 July 2019, Spital/Phyrn):

The Media-Lab activity was successfully implemented in the format of the "International Clean Energy Challenge". It brought together 64 highly-qualified young professionals from more than 30 countries and 11 research and company partners for an event of collaborative innovation. In diversified and interdisciplinary teams, they tackled real-life challenges presented by the partner organisations on specific topics related to energy communities and other important energy transition services.

Each of the 11 teams was assigned to a specific company challenge and the groups worked on business models based on digitisation, value generation with big data, new integrated energy service models, diversifying demand and supply chains, new marketing approaches. The dynamic and structured innovation process consisted of a combination of brainstorming activities, autonomous group work and peer-review sessions. The company representatives were present throughout the entire event and offered valuable support and professional coaching. In the final session, each group presented its solutions to a jury consisting of management-level representatives of the partners as well as the regional energy commissioner. Awards were presented in several categories.

Through contributing to concrete company development processes, the participants gained practical and real-life insights on how driving the energy transition and doing business can go hand-in-hand. The companies profited from the fresh ideas and creative thinking of bright young minds. The participants came from a diversity of educational backgrounds including engineering, economy, architecture, business administration, chemistry, mathematics, law, political science and more.

"International Clean Energy Challenge" also contributed to the exchange with other innovative companies ("community building") as also several companies outside the InduGrid partners joined the event and thereby the innovation and aspiration of the project.

3.5.5 International conference "Industrial Energy Efficiency" (28 February 2019, Wels)

The Industrial Energy Efficiency Conference showed how the energy transition in industry can succeed and which innovations and policies are needed, including how to expand energy communities to industry. The session "Financing and implementing energy efficiency in industry" presented real-life examples on how investments in industrial energy efficiency are possible and economically viable. The following session "Voices for industrial energy efficiency" showcased a variety of energy efficiency and renewable energy projects in industry.
The conference was carried out in the frame of the annual international conference World Sustainable Energy Days (27 February – 1 March 2019, Wels, www.wsed.at).

3.5.6 International conference "Industrial Energy Efficiency" (5 March 2020, Wels)

The second edition of the Industrial Energy Efficiency Conference was held on 5 March 2020. A key theme was how independence from fossil energy is becoming a key factor for industrial competitiveness. Key strategies for this include intensified R&D and collaboration on global, national, regional, and local levels. This requires new collaborations among companies, including the energy exchange between businesses. The session "Energy Efficiency in Action: Leaders in decarbonisation" presented examples of how industrial companies approach these issues, including Indugrid partner Starlim.
The conference was held in the frame of the annual international conference World Sustainable Energy Days (4-6 March 2020, Wels, www.wsed.at).

The conference ensured an exchange with other innovative companies ("community building"). Other industrial and non-industrial companies were informed about InduGrid and this community is used as a gateway for the innovative solutions from InduGrid and other NEFI projects. The international event also contributed to highlighting Austria's leadership in the energy transition.

3.5.7 Innovation Workshops, 25 June 2021, online

As part of the international conference World Sustainable Energy Days, six online workshops were held on 25 June 2021 presenting latest results from EU funded projects in the fields of innovative business models, green finance and technology innovation. The following workshops were held in two parallel livestreams:

- Industrial solar cooling
- "Active buildings" and Energy Contracting
- Business models for deep renovation
- Citizen's financing models
- Pay-for-performance business models
- Innovative renewable solutions

The conference and the innovation workshops were held in the frame of the annual international conference World Sustainable Energy Days (21-25 June 2021, Wels and online, www.wsed.at).

3.5.8 Tagung: “Die neuen Energiegemeinschaften”, 21 April 2021

Emphasis was also placed on engaging the local population within the three project sites and surrounding areas. The event held on April 20th, 2021 ("Tagung: Die neuen Energiegemeinschaften") provided an excellent opportunity to introduce the concept of energy communities to a wider audience. The project coordinator of InduGrid presented typical energy demand-supply structures within energy communities during the event.

4 Results and conclusions

This project InduGrid analyzed the new legal possibilities for the formation of energy communities - especially in the industrial environment.

In the first project phase, the **technical, economic and legal framework conditions** (that changed during the project period) were analyzed. It was found that the technical possibilities for exchanging energy across company boundaries are usually relatively common. In the case of an electrical energy exchange, the public electricity grid can be used for energy transmission in most cases, which means that practically no fundamental technical obstacles are to be expected.
The project also investigated the special case of a direct electrical line between a generator (PV system on the student residence in Hagenberg) and a directly neighboring power consumer (STIWA company). As a result, it was determined that although this possibility exists in principle, it is associated with significant additional effort for the electrical coupling of 2 grid participants and therefore this variant was not realized.

From a **legal perspective**, the “Erneuerbaren-Ausbau-Gesetz” has created the basis for the **exchange of electricity**, whereby a distinction must be made here between renewable energy communities (in the local or regional variants) and citizens’ energy communities. A disadvantage for large companies is the fact that the exchange of electricity can only take place within the framework of a citizens' energy community, which means that some of the economic advantages offered by renewable energy communities cannot be utilized. This naturally has a significant impact on the economic operation of such communities.

The **exchange of heat or waste** heat is much more planning-intensive from a technical point of view. This energy exchange always requires close spatial proximity to minimize grid costs and thermal losses and thus enable economical operation in the first place. From a legal perspective, heat from renewable energy sources can be exchanged within the framework of a renewable energy community, as this is open to all renewable energy sources. There do not appear to be any specific advantages from the fact that heat is exchanged in renewable energy communities instead of a ‘normal’ district or local heating network. In contrast to that, waste heat is not equated with renewable energy sources, so the renewable energy community option is not open to the exchange of waste heat.

In addition to the amount of heat that can be exchanged, the key parameters for heat exchange are, above all, the usable temperature level and the availability and deliverability of the heat provided in terms of time and whether a storage facility, which is usually cost-intensive, must also be provided. It is also essential for the economic assessment of a thermal exchange whether and to what extent a backup heating system needs to be provided.

The second phase of the project InduGrid was dedicated to the development of the software for the **energy exchange platform**. This platform was built to collect all energy relevant data of possible participants in an (renewable) energy community. A web-based platform was created for potential participants to gain relatively quick access to this data. This enables interested companies to create basic energy-related company data and structures and upload already existing consumption profiles.

Instead of the usual method of predefined questionnaires, a customized list of questions in **dashboard- and task-form** was used. This ensured that users were not bothered with too many irrelevant questions and only necessary information had to be provided. Based on this user data (or branches/sector-specific parameters if, for example, no consumption data was provided), possible combinations of energy communities were selected based on pre-calculated economic benefits of joining the energy community. For example, it could happen that an additional participant could not provide any significant benefit either for themselves or for the community and was therefore not accepted into the community.

The decision to participate in an energy community was made based on a **mathematical optimization** problem that can map both electrical and thermal exchange, but also takes into account the energy flow via sector coupling (electricity to heat via heat pumps). This optimization problem solved the task of finding energy flows with the lowest possible costs for all community participants under the given legal and technical framework conditions and considering predefined economic parameters such as electricity and grid costs, heating costs, etc.

With the help of the tools created in advance for the energy exchange platform, it has now been possible to set up and operate **several test sites**:

- In the area of electrical energy exchange, an energy community was realized and put into operation in a rare form with a hydro power plant, which also started its economic operation during the project period (Wels site)

- The case of waste heat utilization at the Ennshafen site between the Salesianer Miettex laundry and the heating customer Biomontan was analyzed in detail; many variants with different price scenarios and various expected energy costs were calculated. In the end, this energy exchange could not be realized because economic operation would only have been possible under very favorable conditions.

- The case of waste heat utilization at the Rübig hardening plant and a heat supply for concrete drying and preheating of output products in concrete production at the Gerstl company was also analyzed and the exchangeable energy quantities estimated. In this case, a new building at Gerstl means that this test plant remains also in the concept phase.

- In contrast, the heat and cold exchange between two STIWA buildings was built up and realized. The novelty here is that only a single heat transfer pipe was required for both heat and cold transport in both directions. To achieve this, new hydraulic control concepts and their parameterization had to be implemented.

- The energy exchange platform was also used to drive forward the planning of a network with a power/heating/cooling plant as an additional energy supplier for a combined heat/electricity exchange in the municipal area of Hagenberg with participating companies, municipal buildings and private individuals.

- The energy exchange platform was also used to simulate an electricity exchange between Wels and Gunskirchen (Formatwerk / PBS companies) and to evaluate the operational framework conditions in a citizen energy community. As two different grid operators were involved in this case, this test case could only be started after the end of the project for legal reasons.

In addition to the technical, economic and legal research, a **stakeholder analysis** was also carried out, as this group plays a key role in the acceptance of the establishment of energy communities and is essential for the introduction of new ideas and the provision of (human) resources for the planning activities.
Even though most stakeholders pay particular attention to implementation and risk assessment => the general attitude of **stakeholders towards energy communities is very positive**.

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6 Appendix

6.1 Test bed Hagenberg

The following tables and pictures present the summary of the annual energy flows and costs of each participant for the different analyzed CHP powers.

6.1.1 Combined heat and power CHP with 200kW

Table 5: Energy flows and costs of the EC for a 200 kW CHP

Participant	Elec. Load Year	Heat Load Year	Costs now	PV Yearly Prod.	PV Selfconsum.	PV_Comm. fed-in
	kWh	kWh	EURO	kWh	kWh	kWh
COUNTIT_2006	50000	100000	9592	18924	14074.8	4849.3
COUNTIT_2020	234000	0	54901	28386	28378.2	7.9
COUNTIT_neu	2028000	454046	586880.6	0	0	0
BC1	1988252.4	157188.8	542854.7	0	0	0
BC2	1988252.4	157188.8	542854.7	0	0	0
VLW	75000	210000	20025	0	0	0
amsec	720984.2	157171	204492.7	0	0	0
IT-Center	1192951.5	94313.3	318518	0	0	0
AuW_Arbeiten	311934.7	105740.4	83286.6	0	0	0
AuW_Wohnen	85000	238000	22695	0	0	0
Studentenwerk	800000	382541	233120.5	172208.6	120309.3	51899.3
FH1_neu	2807999.7	628698	847184.1	0	0	0
FH2	935995	209561.3	249910.7	0	0	0
FH3	467997.7	104781.9	124955.4	0	0	0
ASZ	2997.1	1626.4	412.4	18678	1452.6	17225.4
Gemeindeamt	41200.7	23963.8	11000.6	0	0	0
Bauhof	4940.4	80806.8	1319.1	0	0	0
Musikheim	7475.6	80493.6	1996	0	0	0
Feuerwehr	13732.2	7452	4821.6	0	0	0
Volksschule	2796.5	30111.6	400	10673.2	1298.5	9374.7
Kindergarten	22200	165477	31576.3	0	0	0
Sporthalle	17156	9310	3102	9339	5538.2	3800.8
PV_Anlagen	0	0	0	162689.9	0	162689.9
	13 798 866	**3 398 472**	**3 895 899**	**420 899**	**171 052**	**249 847**

Table 6: Energy flows and costs of the EC for a 200 kW CHP

Participant	PV_Comm. purch.	PV Grid fed	Grid sourced	Elec. from CHP	Heat from CHP	Heat wood chips
	kWh	kWh	kWh	kWh	kWh	kWh
COUNTIT_2006	96.8	0	35222	509.6	0	0
COUNTIT_2020	2318.4	0	198480.5	2504.6	0	0
COUNTIT_neu	38186.1	0	1929697.2	21930.6	106668.7	303914
BC1	37667.3	0	1934956.8	22872.1	0	0
BC2	37667.3	0	1934956.8	22872.1	0	0
VLW	1274	0	71775.2	676.7	0	0
amsec	15042.6	0	726775.2	9029.7	0	0
IT-Center	22462.6	0	1135125.8	12900.5	0	0
AuW_Arbeiten	5873.6	0	296814.4	3373.2	0	0
AuW_Wohnen	1443.9	0	81345.3	766.9	0	0
Studentenwerk	6800.4	0	659032.2	7057.6	60210.8	303044.4
FH1_neu	52873	0	2671888.1	30365.4	147699.6	420816.7
FH2	17624.3	0	890624.7	10121.8	0	0
FH3	8812.1	0	445312.6	5060.9	0	0
ASZ	0.1	0	1519	25.4	0	0
Gemeindeamt	775.8	0	39203.6	445.5	0	0
Bauhof	93	0	4700.9	53.4	0	0
Musikheim	140.8	0	7113.2	80.8	0	0
Feuerwehr	258.6	0	13066.6	148.5	802	6421.8
Volksschule	0.2	0	1473.3	24.4	0	0
Kindergarten	418	0	21123.9	240.1	17808.9	142599.7
Sporthalle	18.3	0	11410.7	170.4	0	0
PV_Anlagen	0	0	0	0	0	0
	249 847	**-**	**13 111 618**	**151 230**	**333 190**	**1 176 797**

Table 7: Energy flows and costs of the EC for a 200 kW CHP

Participant	Costs Community	Elec. Costs before	Heat costs before	Elec. costs after	Heat costs after
	EURO	EURO	EURO	EURO	EURO
COUNTIT_2006	8863.6	9592	0	8863.6	0
COUNTIT_2020	53401.4	54901	0	53401.4	0
COUNTIT_neu	541430.3	541476	45404.6	521949.9	19480.4
BC1	523262.9	542854.7	0	523262.9	0
BC2	523262.9	542854.7	0	523262.9	0
VLW	19388.2	20025	0	19388.2	0
amsec	196696.5	204492.7	0	196696.5	0
IT-Center	307032	318518	0	307032	0
AuW_Arbeiten	80283.2	83286.6	0	80283.2	0
AuW_Wohnen	21973.3	22695	0	21973.3	0
Studentenwerk	185999.4	181477.4	51643	171190.1	14809.4
FH1_neu	749673.4	749735.9	97448.2	722699.8	26973.6
FH2	240898.7	249910.7	0	240898.7	0
FH3	120449.4	124955.4	0	120449.4	0
ASZ	-1575.4	412.4	0	-1575.4	0
Gemeindeamt	10603.9	11000.6	0	10603.9	0
Bauhof	1271.5	1319.1	0	1271.5	0
Musikheim	1924	1996	0	1924	0
Feuerwehr	3800.7	3666.5	1155.1	3534.3	266.4
Volksschule	-684.7	400	0	-684.7	0
Kindergarten	11629.9	5927.4	25648.9	5713.7	5916.3
Sporthalle	2612.8	3102	0	2612.8	0
PV_Anlagen	-18709.3	0	0	-18709.3	0
	3 583 489	**3 674 599**	**221 300**	**3 516 043**	**67 446**

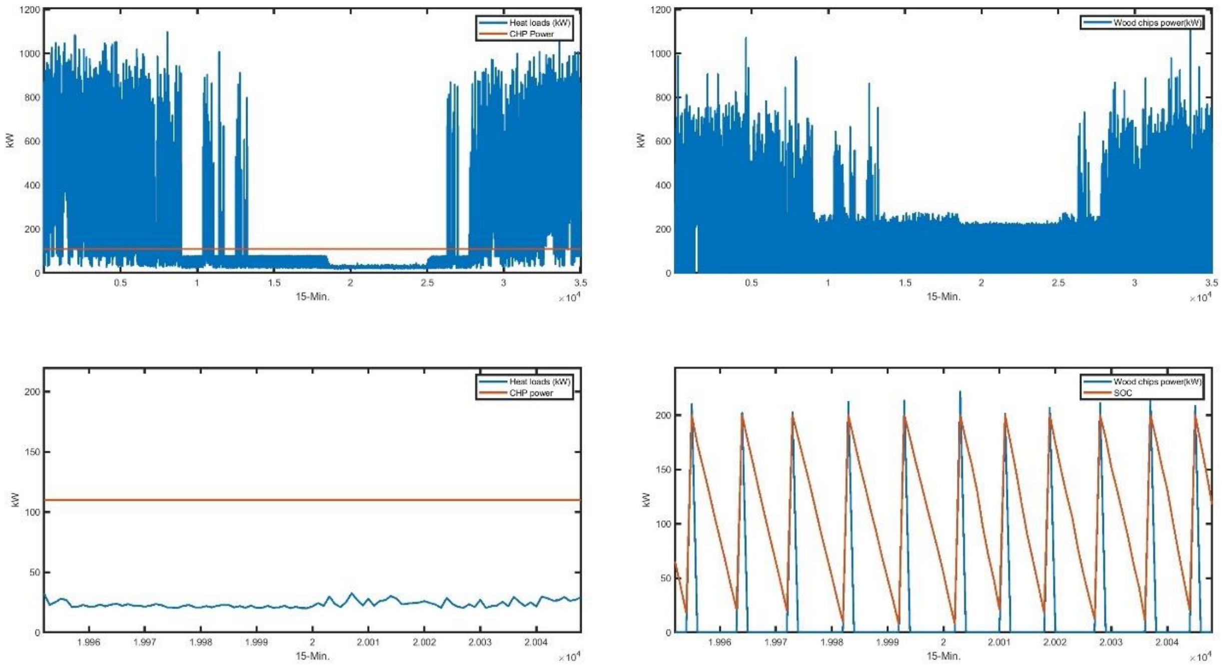

Figure 57: Annual operation (15-minutes time resolution) of the CHP, Woodchips, heat loads of the community, and variations of SoC of the heat puffer for the 200 kW CHP

6.1.2 Combined heat and power CHP with 150kW

Table 8: Energy flows and costs of the EC for a 150 kW CHP

Participant	Elec. Load Year	Heat Load Year	Costs now	PV Yearly Prod.	PV Selfconsum.	PV_Comm. fed-in
	kWh	kWh	EURO	kWh	kWh	kWh
COUNTIT_2006	50000	100000	9592	18924	14074.8	4849.3
COUNTIT_2020	234000	0	54901	28386	28378.2	7.9
COUNTIT_neu	2028000	454046	586880.6	0	0	0
BC1	1988252.4	157188.8	542854.7	0	0	0
BC2	1988252.4	157188.8	542854.7	0	0	0
VLW	75000	210000	20025	0	0	0
amsec	720984.2	157171	204492.7	0	0	0
IT-Center	1192951.5	94313.3	318518	0	0	0
AuW_Arbeiten	311934.7	105740.4	83286.6	0	0	0
AuW_Wohnen	85000	238000	22695	0	0	0
Studentenwerk	800000	382541	233120.5	172208.6	120309.3	51899.3
FH1_neu	2807999.7	628698	847184.1	0	0	0
FH2	935995	209561.3	249910.7	0	0	0
FH3	467997.7	104781.9	124955.4	0	0	0
ASZ	2997.1	1626.4	412.4	18678	1452.6	17225.4
Gemeindeamt	41200.7	23963.8	11000.6	0	0	0
Bauhof	4940.4	80806.8	1319.1	0	0	0
Musikheim	7475.6	80493.6	1996	0	0	0
Feuerwehr	13732.2	7452	4821.6	0	0	0
Volksschule	2796.5	30111.6	400	10673.2	1298.5	9374.7
Kindergarten	22200	165477	31576.3	0	0	0
Sporthalle	17156	9310	3102	9339	5538.2	3800.8
PV_Anlagen	0	0	0	162689.9	0	162689.9
	13 798 866	**3 398 472**	**3 895 899**	**420 899**	**171 052**	**249 847**

Table 9: Energy flows and costs of the EC for a 150 kW CHP

Participant	PV_Comm. purch.	PV Grid fed	Grid sourced	Elec. from CHP	Heat from CHP	Heat wood chips
	kWh	kWh	kWh	kWh	kWh	kWh
COUNTIT_2006	96.8	0	35222	509.6	0	0
COUNTIT_2020	2318.4	0	198480.5	2504.6	0	0
COUNTIT_neu	38186.1	0	1929697.2	21930.6	106668.7	303914
BC1	37667.3	0	1934956.8	22872.1	0	0
BC2	37667.3	0	1934956.8	22872.1	0	0
VLW	1274	0	71775.2	676.7	0	0
amsec	15042.6	0	726775.2	9029.7	0	0
IT-Center	22462.6	0	1135125.8	12900.5	0	0
AuW_Arbeiten	5873.6	0	296814.4	3373.2	0	0
AuW_Wohnen	1443.9	0	81345.3	766.9	0	0
Studentenwerk	6800.4	0	659032.2	7057.6	60210.8	303044.4
FH1_neu	52873	0	2671888.1	30365.4	147699.6	420816.7
FH2	17624.3	0	890624.7	10121.8	0	0
FH3	8812.1	0	445312.6	5060.9	0	0
ASZ	0.1	0	1519	25.4	0	0
Gemeindeamt	775.8	0	39203.6	445.5	0	0
Bauhof	93	0	4700.9	53.4	0	0
Musikheim	140.8	0	7113.2	80.8	0	0
Feuerwehr	258.6	0	13066.6	148.5	802	6421.8
Volksschule	0.2	0	1473.3	24.4	0	0
Kindergarten	418	0	21123.9	240.1	17808.9	142599.7
Sporthalle	18.3	0	11410.7	170.4	0	0
PV_Anlagen	0	0	0	0	0	0
	249 847	**-**	**13 111 618**	**151 230**	**333 190**	**1 176 797**

Table 10: Energy flows and costs of the EC for a 150 kW CHP

Participant	Costs Community	Elec. Cotst before	Heat costs before	Elec. costs after	Heat costs after
	EURO	EURO	EURO	EURO	EURO
COUNTIT_2006	8863.6	9592	0	8863.6	0
COUNTIT_2020	53401.4	54901	0	53401.4	0
COUNTIT_neu	541430.3	541476	45404.6	521949.9	19480.4
BC1	523262.9	542854.7	0	523262.9	0
BC2	523262.9	542854.7	0	523262.9	0
VLW	19388.2	20025	0	19388.2	0
amsec	196696.5	204492.7	0	196696.5	0
IT-Center	307032	318518	0	307032	0
AuW_Arbeiten	80283.2	83286.6	0	80283.2	0
AuW_Wohnen	21973.3	22695	0	21973.3	0
Studentenwerk	185999.4	181477.4	51643	171190.1	14809.4
FH1_neu	749673.4	749735.9	97448.2	722699.8	26973.6
FH2	240898.7	249910.7	0	240898.7	0
FH3	120449.4	124955.4	0	120449.4	0
ASZ	-1575.4	412.4	0	-1575.4	0
Gemeindeamt	10603.9	11000.6	0	10603.9	0
Bauhof	1271.5	1319.1	0	1271.5	0
Musikheim	1924	1996	0	1924	0
Feuerwehr	3800.7	3666.5	1155.1	3534.3	266.4
Volksschule	-684.7	400	0	-684.7	0
Kindergarten	11629.9	5927.4	25648.9	5713.7	5916.3
Sporthalle	2612.8	3102	0	2612.8	0
PV_Anlagen	-18709.3	0	0	-18709.3	0
	3 583 489	**3 674 599**	**221 300**	**3 516 043**	**67 446**

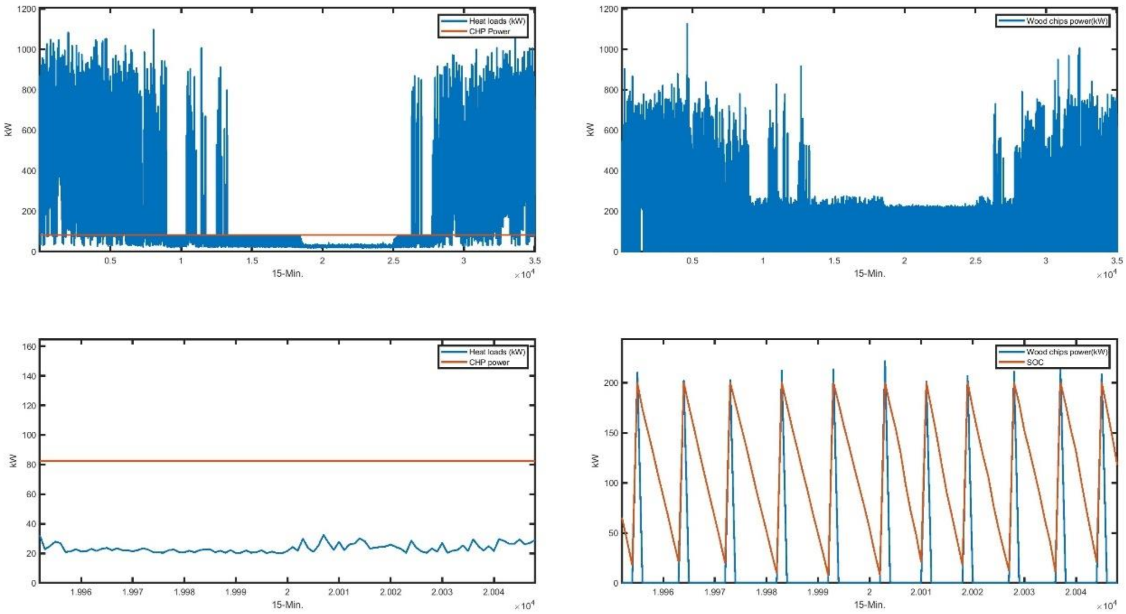

Figure 58: Annual operation (15-minutes time resolution) of the CHP, Woodchips, heat loads of the community, and variations of SoC of the heat puffer for the 150 kW CHP

6.1.3 Combined heat and power CHP with 100kW

Table 11: Energy flows and costs of the EC for a 100 kW CHP

Participant	Elec. Load Year	Heat Load Year	Costs now	PV Yearly Prod.	PV Selfconsum.	PV_Comm. fed-in
	kWh	kWh	EURO	kWh	kWh	kWh
COUNTIT_2006	50000	100000	9592	18924	14074.8	4849.3
COUNTIT_2020	234000	0	54901	28386	28378.2	7.9
COUNTIT_neu	2028000	454046	586880.6	0	0	0
BC1	1988252.4	157188.8	542854.7	0	0	0
BC2	1988252.4	157188.8	542854.7	0	0	0
VLW	75000	210000	20025	0	0	0
amsec	720984.2	157171	204492.7	0	0	0
IT-Center	1192951.5	94313.3	318518	0	0	0
AuW_Arbeiten	311934.7	105740.4	83286.6	0	0	0
AuW_Wohnen	85000	238000	22695	0	0	0
Studentenwerk	800000	382541	233120.5	172208.6	120309.3	51899.3
FH1_neu	2807999.7	628698	847184.1	0	0	0
FH2	935995	209561.3	249910.7	0	0	0
FH3	467997.7	104781.9	124955.4	0	0	0
ASZ	2997.1	1626.4	412.4	18678	1452.6	17225.4
Gemeindeamt	41200.7	23963.8	11000.6	0	0	0
Bauhof	4940.4	80806.8	1319.1	0	0	0
Musikheim	7475.6	80493.6	1996	0	0	0
Feuerwehr	13732.2	7452	4821.6	0	0	0
Volksschule	2796.5	30111.6	400	10673.2	1298.5	9374.7
Kindergarten	22200	165477	31576.3	0	0	0
Sporthalle	17156	9310	3102	9339	5538.2	3800.8
PV_Anlagen	0	0	0	162689.9	0	162689.9
	13 798 866	**3 398 472**	**3 895 899**	**420 899**	**171 052**	**249 847**

Table 12: Energy flows and costs of the EC for a 100 kW CHP

Participant	PV_Comm. purch.	PV Grid fed	Grid sourced	Elec. from CHP	Heat from CHP	Heat wood chips
	kWh	kWh	kWh	kWh	kWh	kWh
COUNTIT_2006	96.8	0	35299.7	431.9	0	0
COUNTIT_2020	2318.4	0	198652.9	2332.2	0	0
COUNTIT_neu	38186.1	0	1931412.8	20215	55158.6	340663.6
BC1	37667.3	0	1937320.3	20508.6	0	0
BC2	37667.3	0	1937320.3	20508.6	0	0
VLW	1274	0	71721.7	730.2	0	0
amsec	15042.6	0	727911.1	7893.8	0	0
IT-Center	22462.6	0	1136135	11891.3	0	0
AuW_Arbeiten	5873.6	0	297078.3	3109.3	0	0
AuW_Wohnen	1443.9	0	81284.6	827.6	0	0
Studentenwerk	6800.4	0	658607.6	7482.2	129195.8	207439.4
FH1_neu	52873	0	2674263.6	27990	76375.7	471702.2
FH2	17624.3	0	891416.5	9329.9	0	0
FH3	8812.1	0	445708.5	4665	0	0
ASZ	0.1	0	1526	18.3	0	0
Gemeindeamt	775.8	0	39238.5	410.7	0	0
Bauhof	93	0	4705.1	49.2	0	0
Musikheim	140.8	0	7119.5	74.5	0	0
Feuerwehr	258.6	0	13078.2	136.9	1981.3	4770.4
Volksschule	0.2	0	1479.9	17.9	0	0
Kindergarten	418	0	21142.7	221.3	43996.1	105930.3
Sporthalle	18.3	0	11442.2	138.9	0	0
PV_Anlagen	0	0	0	0	0	0
	249 847	**-**	**13 123 865**	**138 983**	**306 708**	**1 130 505**

Table 13: Energy flows and costs of the EC for a 100 kW CHP

Participant	Costs Community	Elec. Cotst before	Heat costs before	Elec. costs after	Heat costs after
	EURO	EURO	EURO	EURO	EURO
COUNTIT_2006	8884.4	9592	0	8884.4	0
COUNTIT_2020	53447.5	54901	0	53447.5	0
COUNTIT_neu	537803.1	541476	45404.6	522408	15395.1
BC1	523894	542854.7	0	523894	0
BC2	523894	542854.7	0	523894	0
VLW	19373.9	20025	0	19373.9	0
amsec	196999.8	204492.7	0	196999.8	0
IT-Center	307301.5	318518	0	307301.5	0
AuW_Arbeiten	80353.6	83286.6	0	80353.6	0
AuW_Wohnen	21957.1	22695	0	21957.1	0
Studentenwerk	190012	181477.4	51643	171076.7	18935.3
FH1_neu	744651	749735.9	97448.2	723334	21316.9
FH2	241110.1	249910.7	0	241110.1	0
FH3	120555.1	124955.4	0	120555.1	0
ASZ	-1573.5	412.4	0	-1573.5	0
Gemeindeamt	10613.2	11000.6	0	10613.2	0
Bauhof	1272.6	1319.1	0	1272.6	0
Musikheim	1925.7	1996	0	1925.7	0
Feuerwehr	3873.9	3666.5	1155.1	3537.4	336.5
Volksschule	-682.9	400	0	-682.9	0
Kindergarten	13190.3	5927.4	25648.9	5718.7	7471.6
Sporthalle	2621.2	3102	0	2621.2	0
PV_Anlagen	-18709.3	0	0	-18709.3	0
	3 582 768	**3 674 599**	**221 300**	**3 519 313**	**63 455**

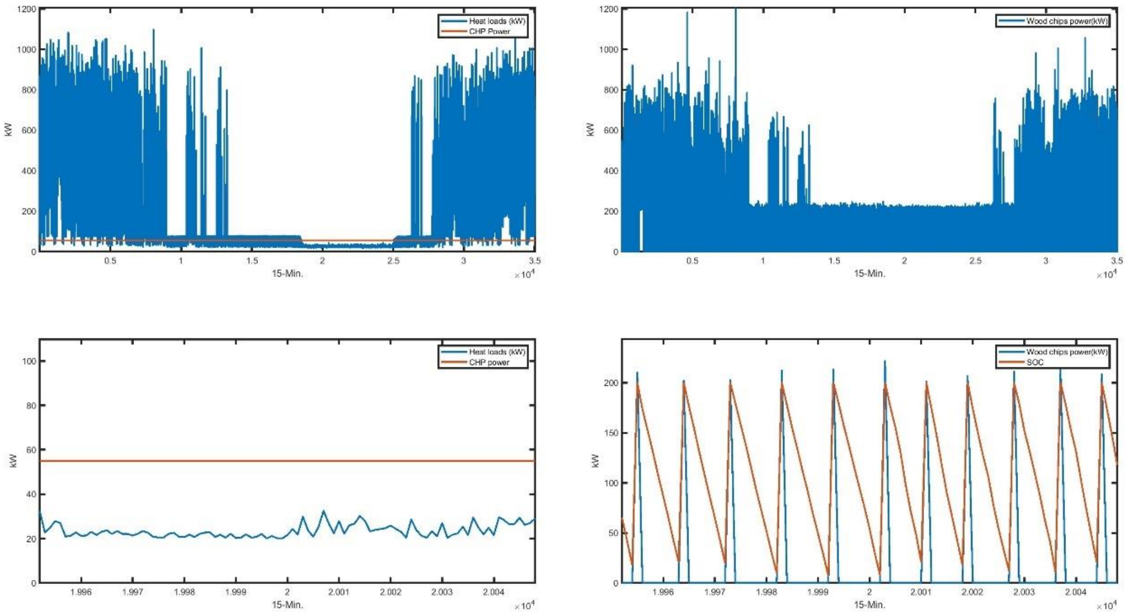

Figure 59: 60Annual operation (15-minutes time resolution) of the CHP, Woodchips, heat loads of the community, and variations of SoC of the heat puffer for the 100 kW CHP

6.1.4 Combined heat and power CHP with 75 kW

Table 14: Energy flows and costs of the EC for a 75 kW CHP

Participant	Elec. Load Year	Heat Load Year	Costs now	PV Yearly Prod.	PV Selfconsum.	PV_Comm. fed-in
	kWh	kWh	EURO	kWh	kWh	kWh
COUNTIT_2006	50000	100000	9592	18924	14074.8	4849.3
COUNTIT_2020	234000	0	54901	28386	28378.2	7.9
COUNTIT_neu	2028000	454046	586880.6	0	0	0
BC1	1988252.4	157188.8	542854.7	0	0	0
BC2	1988252.4	157188.8	542854.7	0	0	0
VLW	75000	210000	20025	0	0	0
amsec	720984.2	157171	204492.7	0	0	0
IT-Center	1192951.5	94313.3	318518	0	0	0
AuW_Arbeiten	311934.7	105740.4	83286.6	0	0	0
AuW_Wohnen	85000	238000	22695	0	0	0
Studentenwerk	800000	382541	233120.5	172208.6	120309.3	51899.3
FH1_neu	2807999.7	628698	847184.1	0	0	0
FH2	935995	209561.3	249910.7	0	0	0
FH3	467997.7	104781.9	124955.4	0	0	0
ASZ	2997.1	1626.4	412.4	18678	1452.6	17225.4
Gemeindeamt	41200.7	23963.8	11000.6	0	0	0
Bauhof	4940.4	80806.8	1319.1	0	0	0
Musikheim	7475.6	80493.6	1996	0	0	0
Feuerwehr	13732.2	7452	4821.6	0	0	0
Volksschule	2796.5	30111.6	400	10673.2	1298.5	9374.7
Kindergarten	22200	165477	31576.3	0	0	0
Sporthalle	17156	9310	3102	9339	5538.2	3800.8
PV_Anlagen	0	0	0	162689.9	0	162689.9
	13 798 866	**3 398 472**	**3 895 899**	**420 899**	**171 052**	**249 847**

Table 15: Energy flows and costs of the EC for a 75 kW CHP

Participant	PV_Comm. purch.	PV Grid fed	Grid sourced	Elec. from CHP	Heat from CHP	Heat wood chips
	kWh	kWh	kWh	kWh	kWh	kWh
COUNTIT_2006	96.8	0	35394.1	337.5	0	0
COUNTIT_2020	2318.4	0	199133.2	1851.8	0	0
COUNTIT_neu	38186.1	0	1935560.4	16067.4	41556.3	347697.4
BC1	37667.3	0	1941558.8	16270.1	0	0
BC2	37667.3	0	1941558.8	16270.1	0	0
VLW	1274	0	71876.4	575.5	0	0
amsec	15042.6	0	729509.6	6295.3	0	0
IT-Center	22462.6	0	1138574.8	9451.5	0	0
AuW_Arbeiten	5873.6	0	297716.2	2471.4	0	0
AuW_Wohnen	1443.9	0	81459.9	652.3	0	0
Studentenwerk	6800.4	0	660223.5	5866.4	104179.5	219665.8
FH1_neu	52873	0	2680006.4	22247.2	57541.2	481441.7
FH2	17624.3	0	893330.8	7415.7	0	0
FH3	8812.1	0	446665.6	3707.8	0	0
ASZ	0.1	0	1530.4	13.9	0	0
Gemeindeamt	775.8	0	39322.7	326.4	0	0
Bauhof	93	0	4715.2	39.1	0	0
Musikheim	140.8	0	7134.8	59.2	0	0
Feuerwehr	258.6	0	13106.3	108.8	1735.5	4790.4
Volksschule	0.2	0	1484.1	13.6	0	0
Kindergarten	418	0	21188.1	175.9	38537.8	106373.7
Sporthalle	18.3	0	11473.4	107.7	0	0
PV_Anlagen	0	0	0	0	0	0
	249 847	**-**	**13 152 524**	**110 325**	**243 550**	**1 159 969**

Table 16: Energy flows and costs of the EC for a 75 kW CHP

Participant	Costs Community	Elec. Cotst before	Heat costs before	Elec. costs after	Heat costs after
	EURO	EURO	EURO	EURO	EURO
COUNTIT_2006	8909.6	9592	0	8909.6	0
COUNTIT_2020	53575.7	54901	0	53575.7	0
COUNTIT_neu	537754.2	541476	45404.6	523515.4	14238.9
BC1	525025.6	542854.7	0	525025.6	0
BC2	525025.6	542854.7	0	525025.6	0
VLW	19415.2	20025	0	19415.2	0
amsec	197426.6	204492.7	0	197426.6	0
IT-Center	307952.9	318518	0	307952.9	0
AuW_Arbeiten	80524	83286.6	0	80524	0
AuW_Wohnen	22003.9	22695	0	22003.9	0
Studentenwerk	188296.4	181477.4	51643	171508.1	16788.3
FH1_neu	744583.3	749735.9	97448.2	724867.4	19715.9
FH2	241621.2	249910.7	0	241621.2	0
FH3	120810.7	124955.4	0	120810.7	0
ASZ	-1572.3	412.4	0	-1572.3	0
Gemeindeamt	10635.7	11000.6	0	10635.7	0
Bauhof	1275.3	1319.1	0	1275.3	0
Musikheim	1929.8	1996	0	1929.8	0
Feuerwehr	3857.4	3666.5	1155.1	3544.9	312.5
Volksschule	-681.8	400	0	-681.8	0
Kindergarten	12669.4	5927.4	25648.9	5730.8	6938.6
Sporthalle	2629.5	3102	0	2629.5	0
PV_Anlagen	-18709.3	0	0	-18709.3	0
	3 584 959	**3 674 599**	**221 300**	**3 526 965**	**57 994**

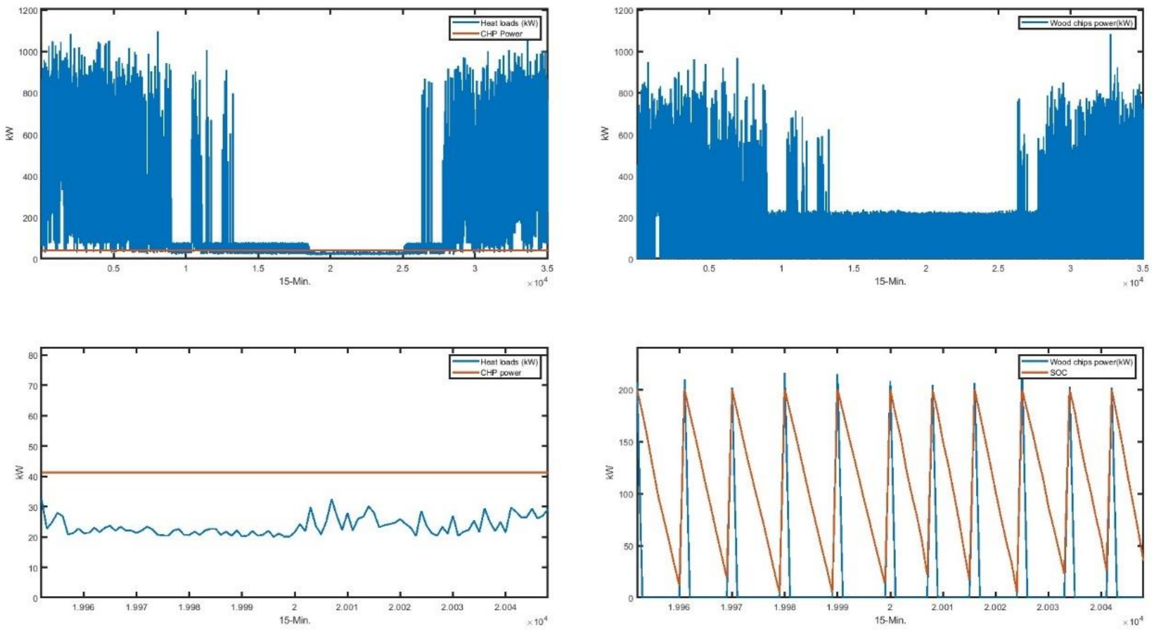

Figure 60: Annual operation (15-minutes time resolution) of the CHP, Woodchips, heat loads of the community, and variations of SoC of the heat puffer for the 75 kW CHP

7 Contact details

7.1 Project coordination

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7.2 List of cooperation partners

- FH OÖ Forschungs-& Entwickungs GmbH
- AIT Austrian Institute of Technology GmbH
- Energiesparverband Oberösterreich
- TU Wien - Institut für Energiesysteme und Elektrische Antriebe, Energy Economics Group
- Energieinstitut an der Johannes Kepler Universität Linz
- Amt der OÖ Landesregierung, Direktion Umwelt und Wasserwirtschaft
- Energie-Control Austria für die Regulierung der Elektrizitäts- und Erdgaswirtschaft
- Wels Strom GmbH
- STIWA AMS GmbH
- ABM automation building messaging GmbH
- Ing. Aigner Wasser-Wärme-Umwelt GmbH
- Rübig Technologie GmbH & Co KG
- Fronius International GmbH
- STARLIM Spritzguß GmbH
- Format Werk GmbH
- Gerstl Bau GmbH & Co KG
- PBS Austria Papier Büro und Schreibwaren GmbH
- Helios-Sonnenstrom-GmbH
- Salesianer Miettex GmbH
- Biomontan Produktions und Handels GmbH