POSSIBLE ACTIONS TO MAXIMIZE THE FLEXIBILITY USAGE IN A DECENTRAL ENERGY SYSTEM FOR THE HEATING AND ELECTRICITY SECTOR

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Abstract: In order to respond to the challenges of climate change, an increasing energy demand and the scarcity of resources, decentralized energy systems will be an important resource to face those challenges. Also interlinking the generation of power and heat, especially on the distribution network level, will yield to new potentials in grid supporting power generation and consumption. It is assumed that a great potential of flexibility exists on the distribution network level (to supply households, industry and businesses), that can be made accessible by coordinated management, including new components, as well as by trading power and balancing energy. Hence the goal of this analysis is to develop a new market role in the distribution network, the Decentralized Market Agent (DMA). Its task is to minimize operation and extension of technologies in the distribution network in terms of cost. In this context the paper responds to the question of which options for action prove to be grid supporting and technically and economically feasible.

For a selection of possible actions a detailed analysis of potential options for action of the market role was conducted. The main areas are demand side management, improving buildings' energy efficiency, extension of the power and heating grid and extension of technologies (renewable energy technologies, storage, renewable and fossil technologies of heat supply). Additionally a case study with some selected possible actions is calculated and presented.

First analyses reveal that several grid supporting options for action exist, that are technical feasible and show revenue potential for the new market role. This revenue can be used for incentives, to reduce obstacles regarding the investment of individual market players.

Keywords: flexibility options, possible actions, DSM, distribution network, power-heat-coupling

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1 Introduction

Various political and societal discussions point towards not to look at a specific sectors and their challenges separately (e.g. power, heat) but to look at the whole systems with its integrated sectors. In order to not only discuss these sectors jointly, but to implement and benefit from interactions various gaps will need to be overcome. Analyzing the current structure also shows that more flexible electrical technologies, storages, power to heat or demand side management will be essential for future renewable based energy systems. However, currently none of the presented market actors pursue the market introduction of such technologies. Lacking not only economic viability, but also a clear assignment of responsibility to existing stakeholders hinders technology deployment.

1.1 Decentralized Market Agent (DMA)

Based on the current structure of the market and in order to reach a more interactive and optimized energy system a new market role is introduced. This new market role (the Decentralized Market Operator, DMA) has the task to operate a regional energy system in an economically optimal way. The DMA targets a cost efficient operation of all system elements. He can control the generation, storage systems, demand side management, while maintaining system stability. The paper [1] provides a more detailed understanding of the DMA concept. Not only can the new market role operate or deploy technologies, but also trade at the central markets for additional revenues. Due to the fact that the DMA has a holistic approach, new business models might occur since some actions might not be necessarily pursued by other stakeholder who are trying to optimize only their sector. Figure 1 presents the concept of the DMA graphically [2]. Based on the prior explanation, the DMA can:

- Operate and deploy decentral heat and power generation technologies
- Operate and deploy decentral storage systems and flexibility technologies like heat pumps, CHP plants or demand side management
- Actively retrofit buildings to higher standards
- Operate and deploy the grids within a decentral system

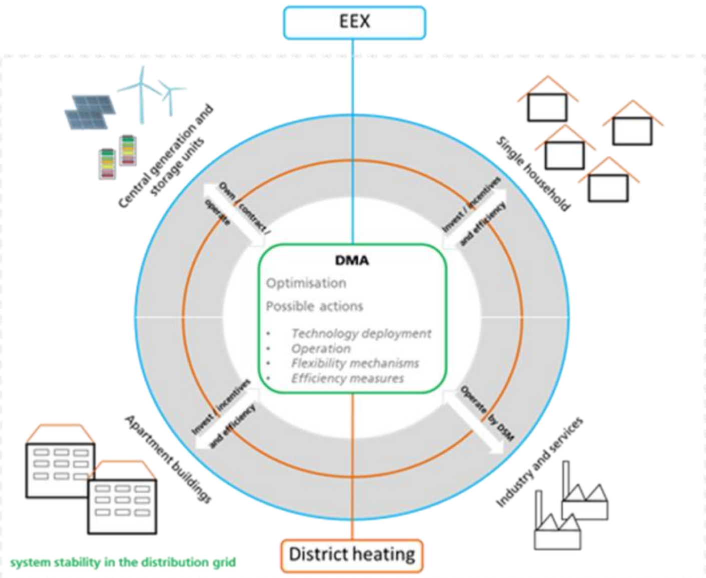

Figure 1: Options for actions, trading and interaction of the Decentralized Market Agent

2 Potential business areas

In this chapter potential business areas are presented. The following table gives an overview of the actions, their potential limits and conflicts that can occur for the DMA.

Table 1: Overview of identified flexibility options, how a DMA could use them and which barriers might occur

	Potential options	Potential limits or conflicts		
		Customers	**Regulation**	**Finance**
Photovoltaic	Incentivize customers to install a certain PV capacity Rent roof area to install own PV system	- Concerns about privacy - Control of equipment placed in their building	- Most installations under EEG or for self-consumption - Self-consumption is now under a reduced EEG fee	- Market environment changing fast - Only low rent for roof top realistic which might be too low for most house owners
Energy Efficiency	Services to apply for energy support mechanisms on energy efficiency measures (insolation of walls, windows, roof and basement ceiling) On-site assistance and consulting for EE measures	- Bureaucratic complexity could be very high - Concern about the scaffolding and the construction work	- The building standards are specified in the energy saving ordinance - The CO_2 building retrofitting program supported by the KfW [3] supports many energy efficiency measures in the building sector	- Expenditures for the services can be high and gains unsure, due to long payback period of investment and influence of consumer on use of energy. - Market environment changing fast
CHP (district)	Operational management of the CHP plant Financial incentive for the investment	- Infrastructural measures like a district heating grid is necessary (see heating grid)	- CHP surcharge for the electricity (act on heat and power cogeneration)	- Bonus or tariff for power plant owner for the provision of flexibility in the distribution grid needed - CHP surcharge in case of electricity or heat driven CHP plant (act on heat and power cogeneration)
Micro CHP (household)	Financial incentive for the investment	- Contractual measures within the house	- Support directive for micro CHP plants - Investment support for mini CHP plants <20kW$_{el}$ for existing buildings	- Investment in technology with unclear operation strategy
	Pooling of mini CHP operated by DMA	- Concerns about delivery of private consumption data - External control of electricity and heating generation		- Bonus for the provision of flexibility for the distribution grid needed for consumer Management and ICT costs
Community size thermal storage	Install and operate community size storage coupled with a district heating system	- Infrastructure might be too complicated - Data provision critical.	- Support of construction or extension of heat storage using CHP heat	- Has to be financed by money saved from using district heating - Smart infrastructure
Heat pumps	When retrofitting the house to a better standards, the DMA can supply a heat pump in exchange for the existing heating system	-The heat supply security might not be completely given - Works only with low temperature heating system	- These exchanges are not in any prior existing regulations - There needs to be a technical consultant in each case to ensure durability	- Heat pump investment too high - Heat demand reduction due to more efficient technology can lead to revenue risk for DMA - Cost for personnel

				operating heat pump as well as infrastructure
Heat pumps	Incentivize the investment and operational management	- Concerns about delivery of private consumption data - External control of electricity and heating generation	- Singular subsidy on investment by BAFA [4] or loan by KfW - No regulation regarding the operational management	- Needed incentives for heat pump investment given by DMA can be high - Heat demand reduction due to more efficient technology can lead to revenue risk for DMA
District heating	Grid installation or grid expansion and operation (investment incentive)	- Compulsory connection disagreement - Contract durations too long	- No regulation to control the district heating stakeholders and competitiveness - Contracts are long term and lack flexibility	- Investment in grid infrastructure is high and needs to be amortized over a long period.
	Develop mini heat grids (building to building)	- Operational and management issues too complex for customer	- No regulations supporting or protecting this connection between private buildings	- Investment in infrastructure can be high.
Small thermal storage	Incentivize the investment and operational management in combination with heat pump or mini CHP	- Concerns about delivery of private data - External management of heating system - Bureaucracy	- Singular subsidy on investment by BAFA or loan by KfW - No regulation regarding the operational management	- Costs for personal for management and ICT infrastructure can be high.
Solar Thermal Power	Investment incentive Service for application for public	- Technology only as secondary heating system	- Support by BAFA or KfW	- Costs for service personal for can be high.
Demand side management	Use demand flexibility against monthly payment / reduced electricity tariff	- Necessary financial reward difficult to determine, flexibility potential in private households quite limited - Threat of rebound effect	- No regulation yet which allows to receive detailed demand information - Uncertainty on how far a third party is allowed to intervene in private consumption	- Quantity of necessary payments and incentives still to be determined - Additional costs have not been examined to full extent
Electricity Grid	Grid service through grid-supporting operation of CHPs and batteries or their spatial allocation Service as a grid planer: Decision/recommendation where to expand grid or imply smart grid options such as OLTC-Transformators	- High uncertainty about communication link between DSO and others like DMA - Plus: general hesitation to grid expansion (due to expropriation proceedings) and uncertainty about smart grid functionalities	- If DMA != DSO → no business model existent (except: Bonus for CHP operators if they operate during highest peak of year) - Generally: current regulation does not directly allow for non-classical, “better” options to be accounted for → however, amendment of “Anreizregulierungs-Verordnung” being discussed	
Industrial DSM	Load shifting of industrial processes by the DMA (taking into account the operational restrictions)	- Possible losses in product quality by interventions in operational procedures - Efficiency losses	- Need for pre-qualification of industrial load management potentials - Provide control	- Revenues from the flexibility offer need to compensate for the intervention in operational autonomy and the cost to

		due to development/ utilization of potentials - Disclosure of detailed confidential operating data	interface standardization - Flexibility of the structure of the regular network charge and the provisions of Section 19 StromNEV - As appropriate: flexible electricity tariffs	develop, provide and use the potential - Planning security for any necessary investment must be given
Electrification of thermal processes	Increases in combination with thermal storage the flexibility	- Investment in production facilities and storages - Electricity costs currently exceed fuel costs - Efficiency losses due to development/ utilization of potentials - Disclosure of detailed operating data		

Based on the objectives of the new market role, the possible actions are selected. In the tables presented in the previous section, a list of most possible actions and business areas are presented. For the current paper, only a number of actions are explained in more detail. The criteria for the selection are based on the technical as well as the economic feasibility of deployed actions. According to a qualitative analysis the above mentioned business areas are evaluated in a first step. The doability of each action is evaluated according to the current barriers, the potential benefits to the system and to the DMA. Other factors that influence the selection are the future system configurations and innovative solutions.

2.1 Selected business areas

In this section the analysis of the different potential business areas is discussed. Based on the selection criteria presented in the previous chapter the following business cases have been selected to be discussed in more detail.

- Combined Heat and Power (CHP) (Central)
- Micro CHP plants
- Heat pumps
- Thermal storage
- Electricity Grid
- Demand Side Management (DSM) in the industry
- Electrification of thermal processes

Electricity Grid

The electrical grid supplies connected customers with electric energy at all times. Hence the electrical grid needs to cover all peaks of load and production to guarantee a certain quality of supply for customers and to prevent damage of grid assets. Quality of supply means to keep voltage in a certain range. Damage in grid assets is avoided when assets don’t have to carry more current than their maximum load.

Hence if peaks rise the grid needs to be reinforced to cover the new peak. When the overall cost of the energy system is optimized, electrical consumers and producers can be influenced to weaken grid peaks. Peaks depend on two factors. On the one hand the location of consumers and producers in the grid. On the other hand peaks depend on time and height of power production and consumption. The crucial question is if it is cheaper for the energy system to reinforce the grid or to take the restrictions into account that arise when peaks shall not rise due to a change in consumption and production infrastructure.

DSM in the industry

Demand side management in this context does not refer to price signals or similar soft incentives, but means the allowance of the DMA to directly interfere with the industrial energy demand, in order to increase or decrease it temporarily. Further, in this context only load shifting potentials are considered. Thus it is assumed that the load reduced at a certain point in time is pre- resp. postponed within a defined time frame for management and no load is shed. Hence no opportunity costs for production losses have to be considered. The interference by the DMA still influences the companies' workflows and as the case may be also the product quality. It also requires disclosing detailed operational data to the DMA. Further, the load management potentials need to be pre-qualified and control interfaces for the communication between DMA and industries need to be standardized. Therefore, the incentives for industrial companies need to compensate these hindrances. Additionally, the use of load shifting potentials is often accompanied by efficiency losses due to inefficient modes of operations. However, this aspect is not considered in this optimization problem due to high complexity and insufficient data availability [6].

Electrification of thermal processes

In a system aiming towards a high share of renewable energy, electricity can become one major energy source for heat appliances: especially controllable high temperature applications cannot be supplied by solar thermal or geothermal energy sources. The potential for biogas/biomass, which could serve that need, is limited. Therefore direct usage of electricity for heat appliances can be an attractive alternative from the system's point of view. In addition, thermal storage is superior to electricity storage. Therefore, applying thermal storages in combination with the electrification of thermal processes, results in an additional flexibility for the electricity sector [6]. But this requires investments in new plants (electric heat appliances and thermal storages), which are not attractive under current conditions. In addition, gas is still cheaper than electricity. Therefore, the possible benefit for the system needs to be opposed to those additional costs, and needs to be translated into incentives or compensations for the investment.

CHP (Central), Micro CHP Plants, Heat Pumps, Thermal Storage

Because of the complexity and the high number of possible actions and their interconnectivity, the following section presents technologies like CHP, Heat pumps, Heating grids and Storage systems collectively and calculated as a case study via a model in the following chapter.

Due to falling electricity prices the additional revenues generated from the sale of electricity generated in CHP plants declining and endanger the economic feasibility of whole district heating projects [5]. Additionally an increased number of energy efficiency measures decrease the amount of sold heat and hence reduce the total contribution margin for covering the operation and maintenance of the grid and for refinancing of the initial investments. To remain profitable, district heating operators need to find answers to these arising issues.

Even though low electricity prices are traditionally undesired for CHP projects, they can become an opportunity, if electricity is used to generate heat using heat pumps. Depending on price levels and availability, electricity for heat pumps can either be generated with PV, CHP plants or purchased from the grid. If electricity prices are high, it is assumed that conventional CHP operation with electricity sale is more economic. However, conventional district heating flow temperatures are way too high for efficient CHP operation. To reduce the flow temperatures to suitable levels for heat pumps, each of the connected houses either is supplied by low-temperature heat or needs to be disconnected. In chapter 3 of this paper more detailed investigations of this case are conducted, where it is assumed that the DMA is able to incentivize energy efficiency measures in all connected buildings in order to be able to operate the grid at lower temperature levels and use heat pumps for heat generation.

3 Case Study

The economic feasibility of district heat supply by heat pumps is examined with regard to eight multi-family apartment buildings with connected by a heating grid in the Freiburg's neighborhood Weingarten. Detailed building and resident information are given in the Annex. The total population of the area is 512 people living on 16,228 m². Thermal and electric load profiles are generated based on real building data and statistical information for each individual building by using the software SynPro [7].

3.1 Scope of the case study

Total heat demand in the system is 1,755 MWh/a where hot water demand accounts for 30 %. If building retrofitting measures are carried out, the demand for space heating reduces to 627 MWh/a and the share of hot water demand increases to 46 % of the total heat demand. The specific demand for room heating prior to the retrofitting measures is 76 kWh/(m² a). While this seems too low at the first glance, it becomes plausible considering the fact that some basic retrofitting measures have already been carried out and given the low surface-volume-ratio of these big buildings.

The present preliminary analysis only examines the possibilities for heat generation in the central heating plant. Extension and operation of the heating grid are currently not within the scope.

In the study two cases are compared to each other. One is the conventional district heating system with a condensing gas boilers and natural gas CHP units. Electricity can either be sold to customers or fed into the grid. The other one is the DMA case, where the DMA incentivizes retrofitting measures of the buildings and is consequently able to use heat pumps for heat supply. In both cases it is possible to install PV systems on the building's rooftops with a maximum capacity potential of 320 kW_p.

3.2 Methodology

To asses and compare both cases a model in the mathematical modeling language GAMS was developed. The model takes investment costs as annuities, variable operating costs, expenses for energy purchases, taxes and fees, as well as revenues from electricity sale and subsidies into account. The objective function, defined as the sum of total cost minus the total revenues is minimized. Hence, the model performs an integrated optimization of the capacity installed and operation without dictating technology deployment. The output is the system configuration and operation, with minimal cost for the energy supply of the neighborhood.

3.3 Subsidies and taxes

Since taxes and subsidies play an important role in energy system operation, the most influencing regulations are represented in the model. For electricity consumed close to the location of generation there is a tax exemption. Hence, electricity taxes are only considered for electricity withdrawn from the grid.

For electricity consumed by the DMA (e.g. for heat production), the renewable energy fee of 6.354 €ct./kWh is incurred. If the electricity is generated on-site in a CHP unit or by PV systems, there is a reduction to 40 %. Electricity consumed by domestic end consumer has to be charged by the full fee, independently of the location of production.

Regarding the electricity from CHP units or PV systems sold to customers or fed into the grid the DMA receives a feed in premium of 6 €ct./kWh or 7.47 ct./kWh (corresponding to a PV feed-in-tariff of 11.09 €ct./kWh) respectively. Since the CHP law in Germany imposes a limit of the premium to 30,000 full utilization hours, this is reflected in the model by introducing a limit for premium payments of 2,000 full utilization hours per year. Locally produced electricity sold to customers is charged with the full grid fees. Therefore 4.18 €ct./kWh are withdrawn from the premium for electricity not consumed by the DMA or fed into the grid.

All other regulations, taxes and price components are considered of minor importance for the present analysis.

3.4 Results

Table 2: Overview of installed capacities and full utilization hours for both cases

	DMA		Conventional	
Technology	Installed Capacity	Full utilization hours	Installed Capacity	Full utilization hours
CHP unit	155 kW_{el}	2,705	180 kW_{el}	2,000
Natural gas boiler	163 kW_{th}	1,284	422 kW_{th}	3,213
Air heat pump	21 kW_{el} 82 kW_{th}	5,108		
PV systems	320 kW_p	944	320 kW_p	944
Hot water storage	795 kWh_{th}		755 kW_{th}	
High temperature heat storage	1,494 kWh_{th}		1,689 kW_{th}	

As the results in Table 2 show, the possibility of using electricity to generate heat causes a significant reduction in installed fossil capacity in the DMA case. In contrast, the conventional scenario shows that the heat is mainly generated by boilers. Even in the summer days, when the CHP unit is running with minimal capacity, the boilers are in operation. Due to the premium limit of 30.000 full utilization hours, the CHP unit only operates during the periods of highest electricity prices. However, the assumption, that the hours accountable for the feed-in-premium are distributed equally over the lifetime of the CHP unit is questionable. It is assumed, that during the initial years, operation hours will be higher and once the premium as expired, the operator will decide on technology deployment solely by considering variable operating costs.

In both scenarios the PV potential is used to the maximum. The grid fees for locally generated electricity make selling CHP electricity without claiming the premium infeasible. However in the DMA scenario the CHP plant runs for more than 2,000 hours. The additional electricity generated by the CHP unit is used to power the heat pump, since variable costs of CHP operation are cheaper than purchasing electricity if grid and renewable fees are taken into account. Low temperature thermal storage systems are not installed in both cases, since the temperature spread is only 10°C, which increases the necessary volume of storage per kWh and causes high specific costs for low temperature storage. The heat output generated from the heat pump is either consumed directly or increased to a higher temperature level by the boiler or the CHP plant.

3.4.1 Operation in winter

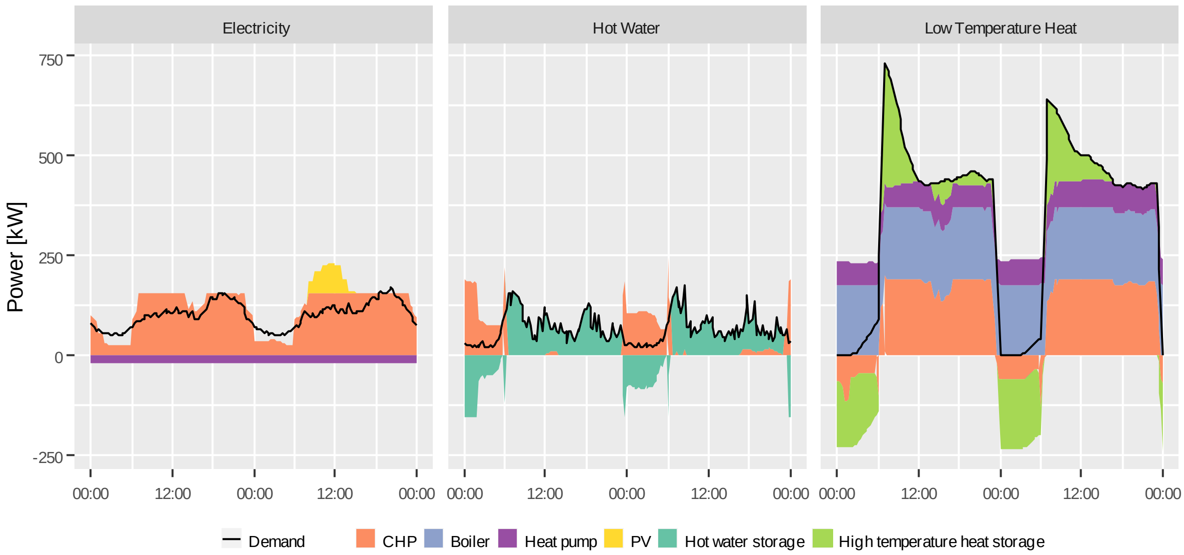

Figure 2 Load and generation profiles for DMA case on January 6th and 7th

As can be seen in Figure 3 the heat pump operates at base load in the winter and continuously produces low temperature heat. This mode of operation it is more efficient than generating hot water. During the day the heat is immediately consumed, whereas at night the CHP converts the heat pump output to hot water temperature level and charges the hot water storage. At night high temperature heat generated by the boiler is loaded into the storage. The storage content is used to cover the morning peak heat demand, reducing the necessary installed boiler capacity.

3.4.2 Operation in summer

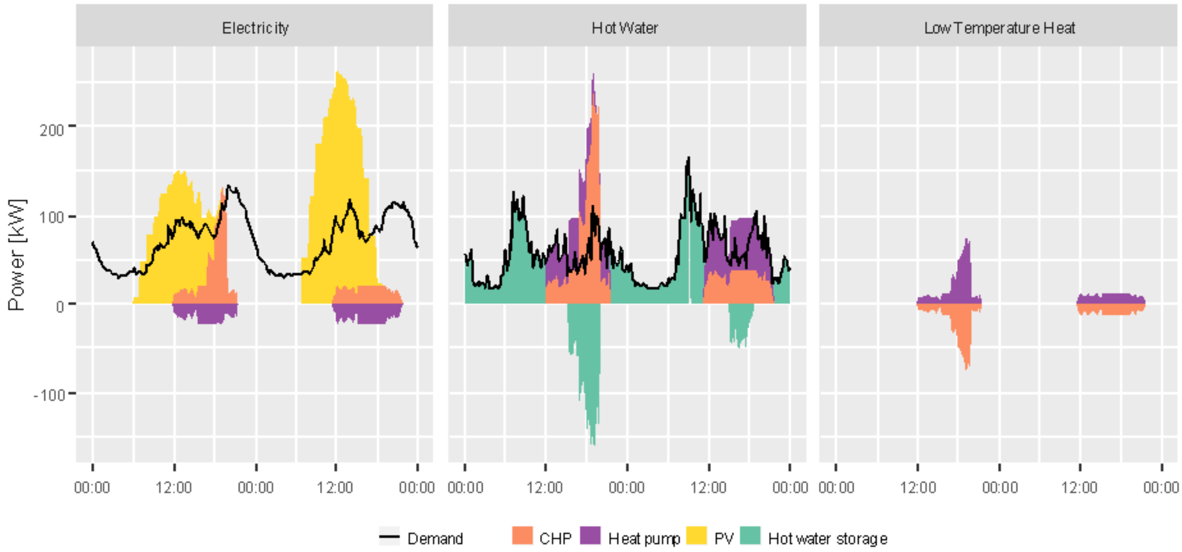

Figure 3 Load and generation profiles for DMA case on July 4th and 5th

In summer the CHP unit and the heat pump operate simultaneously during the hours of the day with the highest ambient temperatures, because this ensures best efficiencies of the heat pump process. As in winter, low temperature output of the heat pump is heated up by the CHP unit to the hot water level. Due to higher ambient temperatures a direct hot water generation by the heat pump is economically feasible, too. In periods with high electricity prices and no PV generation, the CHP unit supplies the electricity demand. However, during periods with lower prices, electricity is purchased from the grid.

3.4.3 Assessment of results

The marginal cost of electricity generated in the CHP unit is 11.6 €ct./kWh, if heat is priced with the marginal costs of heat generation in the boiler. For most hours of the year this is much cheaper than the costs for consumption of self-generated PV electricity, when considering the renewable energy fee of 40% paid for self consumption. This is because of the passed on income when selling at the EPEX plus the market premium. The high feed-in-premium and the taxation of self-generated electricity with the renewable energy fee leads to a – from a local perspective – bizarre situation where it is more economic to operate the CHP unit even though there is an excess of PV electricity present.

Table 3: Weighted average electricity prices during operation of electricity related equipment

<table>
<tr><th></th><th>DMA</th><th>Conventional</th></tr>
<tr><td>EPEX average</td><td colspan="2">3.46 ct./kWh</td></tr>
<tr><td>CHP</td><td>4.47 ct./kWh</td><td>4.81 ct./kWh</td></tr>
<tr><td>Air heat pump</td><td>3.8 ct./kWh</td><td></td></tr>
</table>

As can be seen in Table 3, the electricity generated by CHP has a higher value in both cases than the average electricity price. The plant is operated in both cases in the hours with the highest electricity prices. Since the amount of hours in the DMA case is higher, the electricity value is slightly lower. Additionally, it can be noted that the electricity consumed by the heat pump is higher than the average price in 2014. This is due to two facts: Firstly the wholesale electricity price is blurred by grid fees and taxes. Secondly, the heat pump is preferably operated during the day because the effect of higher ambient temperatures on the COP is more important for the profitability, than the electricity price

4 Conclusions

Based on our analysis in the previous sections and the results of the model, it can be concluded that there is high potential of flexibilities in the decentral system. A new market role can contribute in optimally using the flexibilities in a cost optimal way. Not only does he provide a safe supply and system stability but he can create new market niches and business opportunities by combining or pooling different technologies as well as utilizing options like DSM or energy efficiency.

With current market conditions and the underlying assumptions, the initial idea of installing a CHP unit in combination with an air heat pump for a district heating supply in order to be able to react more flexible to electricity prices and increase the self-consumption of PV electricity does prove itself to be true. In the model calculations only 0.08 % of the generated PV electricity where consumed by the heat pump and no electricity is retrieved from the grid to generate heat. However, the German government announced to reform energy system regulation [8] and the electricity prices are supposed to have a wider variation in the future. Hence, it is likely to assume, that the initially sketched operation mode will turn profitable in the near future.

Nevertheless, embedding heat pumps in local energy systems joint with heat storages, boilers and CHP units already provides a great flexibility option: The possibility of operating the heat pump when ambient temperatures are above-average to achieve a very high average COP. In the model calculations, the yearly average COP was 4.1, which is even higher than the design COP of the heat pump. In combination with the CHP unit 1 kWh of natural gas was turned on average into 2.13 kWh of heat. The total amount of heat supplied by the heat pump was 447 MWh/a. In comparison to generation of the same amount of heat in a condensing boiler, this saves 137 MWh/a of gas, corresponding to annual savings of another 6,900 € or 27.4 tons of CO_2. Because of the lower installed capacities in the DMA case, yearly capital costs save another 1,400 €. These annual savings of 8,300 € could be used by the DMA to incentivize retrofitting measures in the connected buildings, which will save another 607 MWh/a or 30,655 € per year for the customers.

Further investigation is needed to assess implications on the heating grid. Lowering the flow temperatures and the temperature spread will increase the necessary mass flows and hence electricity consumption in pumps. Contrary, lower flow temperatures correspond to fewer grid losses which might compensate for the increased demand of pumping energy. Also, it will be necessary to assess whether a second parallel heating grid will be necessary to supply heat and hot water simultaneously. Conceivably the grid flow temperature could be increased at night when no heating demand is present to charge decentralized hot water storages.

To conclude, it is safe to say that having a system oriented actor in the market on a decentral level can be beneficial to the system and creates potential technological variations that might not take place in the current system configuration.

Acknowledgment

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6 ANNEX

6.1 Building data and heat demand

Table 4: Data on buildings and residents for the area within the scope of the analysis

	Building data		Demand [MWh/a]			
	Area [m²]	*Residents*	*Electricity*	*Hot water*	*Heating*	*Heating refurbished*
Building 1	2,240	64	93.5	65.5	145.6	83.1
Building 2	1,958	64	90.7	65.2	161.0	81.8
Building 3	1,958	64	88.8	65.3	161.8	82.5
Building 4	1,958	64	93.7	65.2	160.2	81.7
Building 5	1,958	64	92.4	64.7	161.2	81.8
Building 6	1,958	64	89.0	65.4	161.4	81.6
Building 7	1,958	64	92.7	68.0	139.1	66.4
Building 8	2,240	64	92.2	67.9	138.2	68.0
Sum	16,228	512	732.9	527.1	1,228.5	626.9

6.2 Energy prices

Table 5: Assumptions concerning energy prices for the model calculations

Energy	Price
Natural gas	4.55 ct./kWh (upper heating value) [9]
Electricity feed in	EPEX Spot Day Ahead prices for 2014 with hourly resolution, average value: 3,46 ct./kWh [10] + CHP feed-in-premium: 6 ct./kWh + PV feed-in-premium 7.47 ct./kWh
Electricity purchasing	EPEX Spot Day Ahead prices for 2014 with hourly resolution + grid fees: 4.18 ct./kWh [11] + electricity tax: 2.05 ct./kWh

6.3 Technology data

Table 6: Technology data assumptions for the model calculations. Values derived from [12], [13], [14] and [15]

Technology	Fixed costs	Lifetime	Efficiency	Variable costs
Gas boiler	175 €/kW	20 a	106 % for high temperature 109 % for low temperature For lower heating values	
CHP	1000 €/kW_{el}	15 a	40 % electrical 49 % thermal For lower heating values	1.2 ct./kWh_{el}
Air heat pump	780 €/kW_{th} 3042 €/kW_{el}	20 a	Coefficient of performance (COP) 3.9 at A2/W35 Bilinear fit to account for influence of ambient and flow temperature	
Heat storage	Dependent on temperature levels: Low: 86 €/kWh High: 22 €/kWh Hot water: 20 €/kWh	20 a	99 % for low temperature 97 % for high temperature 98 % for hot water	
PV systems	1400 €/kW_p	25 a	944 kWh_{el}/kW_p	

6.4 Temperature levels

When dealing with heat pumps, temperature levels have a major influence on performance. Therefore it is not possible to balance simply the energy amounts but temperature dependency has to be accounted for. In order to keep the model linear, three temperature levels are defined, as shown in Table 7.

Table 7: Temperature level definitions

Level	Flow temperature	Spread	Purpose
Low temperature heat	30° C to 45° C	10° C	Heating of retrofitted buildings
Hot water	60° C		Hot drinking water consumption
High temperature heat	60° C to 90° C	30° C	Heating of not-retrofitted buildings