The economic aspect of using flexibilities

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ABSTRACT

Higher shares of RES lead to higher necessities of flexibilities in the energy system. Within this paper, the economic aspect of two high promising flexibility options are analysed for the purpose of further usage within the smart-city-project *Hybrid Grids Demo*, which will demonstrate the facilitation of flexibilities in a living lab approach within the city of Hartberg, Styria:
(1) Households using their heating devices such as heat pumps, heat water boilers and electrical space heating
(2) The heating grid of the city by enabling its flexibilities for the electricity grid by the usage of a central heat pump in addition to the existing CHP

KEYWORDS

Flexibilities, hybrid grids, sector coupling, power to heat, economic analysation, RES integration

INTRODUCTION

Motivation and background

During the last couple of years, the necessity of flexibilities for the energy system has grown significantly, driven by an increased amount of RES and their volatile and intermittent generation characteristic.

Currently heat systems are one of the key appliances to provide flexibility in households [1], which can, under certain circumstances, provide a benefit to the electrical energy system. This is further approved when considering the economic aspects in a European setting [2], where the results of the economic analysation of flexibility provision on household level suggests, that only using heat pumps is economically feasible. One key challenge with household flexibility is, that economic feasibility is most likely reached when considering an aggregator, while the financial benefit for the single household is somewhat limited [3]. This doesn't leave many options for the flexibility owner's themselves. With the increase of RES, especially PV, for households using flexibilities to increase the self-consumption is becoming more attractive [4]. This leads to a priority dilemma, since the flexibility use can either be in favour of the pooler or the single user, in each case limiting or eradicating the benefit for the other. What is needed is a two-layered strategy for using household flexibilities to create benefits for both parties, the pooler and the flexibility owners.

The necessity of creating flexibilities for the energy system for the integration of RES in power grids is accompanied with another issue. Local heating grids have often been built using state subsidies. These are mostly investment subsidies for pure heating grids or tariff subsidies for heating grids, whose heat generation happens via CHP [5, 6]. Especially in the case of the latter, the economic question arises after tariff promotion has expired. Due to fuel costs, feeding in electricity at market prices as a band load often makes no economic sense. On the other hand, there are heat supply obligations that must be complied with and whose characteristics do not always coincide with the requirements of the electricity market. Power-to-heat is therefore often seen as a possible supplement to heating grids to counter low electricity market prices in two respects. On the one hand, the power of the CHP can be reduced, when market prices don't allow economic operation. On the other hand, RES-surplus at low electricity prices used in Power-to-heat-devices can be used to cover the heating demand of the grid [7, 8, 9]. The decisive factor is the advantage that can be achieved in the running costs of heat generation by Power-to-heat systems. This represents an essential basis for investment decisions in the heating network.

This paper addresses the issue of this two-layered flexibility use on household level. By implementing a simulation model to use the flexibility for self-consumption maximisation and liberalised market price optimisation the general economic benefits for both the flexibility provider (household) and flexibility user (pooler or energy supplier) will be shown. Considering data forecasts the system will ensure the prioritisation of self-consumption over market price driven use, while making sure, that the comfort levels of the flexibility providers are kept. To quantify the financial benefits the two benchmarks (1) own-consumption rate for households and (2) average market prices are used.

For the heating grid this paper includes an analysis for three scenarios for heating production in the existing heating grid of *Hybrid Grids Demo* after the end of the tariff promotion. The baseline scenario 1 shows the economic impact of the current power-driven strategy, baseline scenario 2 represents heat-driven operation and whereas the flexibility scenario shows a rule based power to heat strategy in combination of the CHP with a heat pump, which can be supplied by local RES-surplus or electricity from the grid.

Both strategies shall be implemented during the demonstration phase of *Hybrid Grids Demo*. This project is funded by the Climate and Energy Fund and implemented under the Smart Cities Demo program.

METHODOLOGY FOR THE UTILISATION OF FLEXIBILITES

The goal of the project Hybrid Grids Demo is the use of flexibilities in a hybrid energy grid environment to ensure that the energy system will be capable to handle high shares of RES in the future. The activation of energy flexibilities always requires some sort of storage capacity [10], these can be actual material storages in case of production lines, electrochemical storages such as batteries or thermal storages such as heat water storages etc. The challenge is to identify a storage system with low enough investment costs to be refinanced by the flexibility use. As battery storage systems are currently still very expensive [11], these were not an option in Hybrid Grids Demo. For that reason, the approach of sector coupling was chosen, combining cheap storage capacities in the thermal system with the need of flexibilities in the electrical system, thus creating a hybrid energy approach. Two different types of flexibilities were identified, investigated and are going to be demonstrated during the project: (1) Heating devices in households and (2) the local heating grid at the demonstration sites. These two types of flexibilities are combined to one system as depicted in Figure 1. The hybrid energy system developed in this project is operated by the local energy supplier and grid operator. Due to the size of the local energy supplier grid operation and energy sales are no subject to unbundling, thus benefits of flexibility operations can be yielded at different sectors. The mode of system operation includes a centralised optimisation unit (central controller) which will send out suggestions to the flexibilities. The local users can then decide, either on single suggestion basis or in general, whether they want to accept the suggestion or decline the request. That way full autonomy of the single user is ensured, while a system optimal use of resources is aimed for.

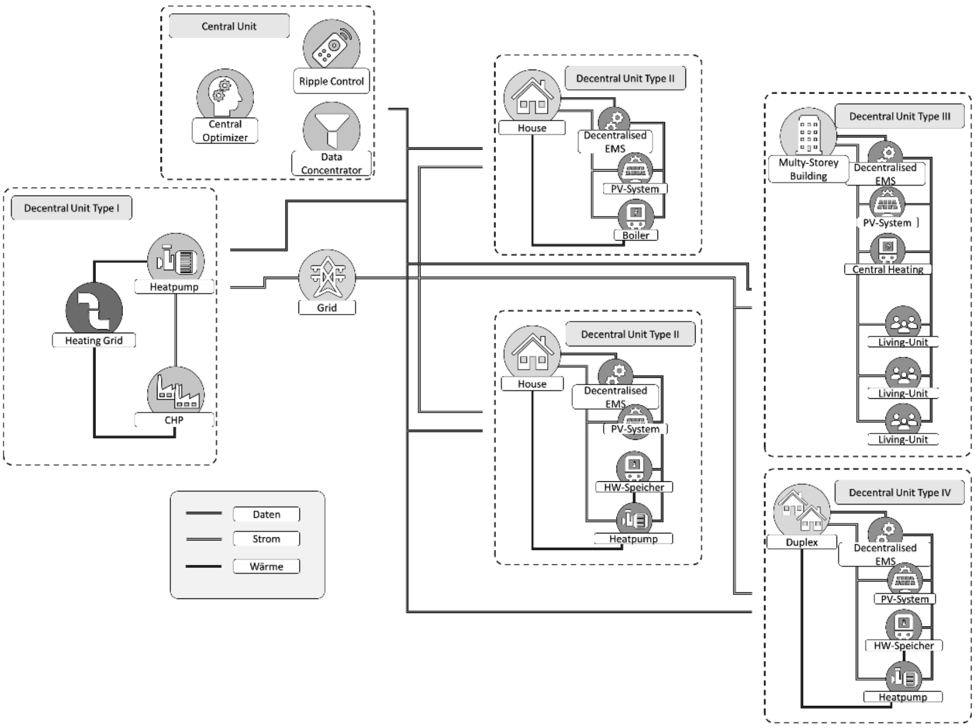

Figure 1: Coupling of heat and electricity to create a hybrid energy system

Heating Devices in Households

The challenge with using flexibilities provided by households is the fact, that the storage capacities and thus the economic possibility are limited. To create flexibility in the electrical energy system by facilitating thermal storage units, the heat generation must happen with electrical energy. For that case the following heat generating appliances (HGA) are considered: (1) heat water boilers and (2) heat pumps, with the second being capable of generating thermal energy exclusively for heating or for heating and warm water.

The users/owners of the households or flexibility provider (FP) providing the flexibility for the energy system will require an incentive to actively invest into the system enabling the use of flexibilities. The energy supplier/grid operator or flexibility user (FU) will then use the flexibility for his own benefit.

To better understand the effects on the provision of heat and warm water and to be able to quantify the economic benefits for the FU as well as the FP a techno-economic simulation model was created.

Simulation model for the optimised use of the household flexibility

As already mentioned, the household flexibilities are “controlled” by a central intelligence via operation suggestions. To create an incentive for the FP to provide their flexibility and accept the suggestions of the central intelligence an economic benefit must result for them. On the other hand, the FU must also have a benefit from operating the central intelligence unit. Therefore, a two-step approach was developed and implemented, which can be seen in Figure 2. A detailed description of the approach can be found in [12].

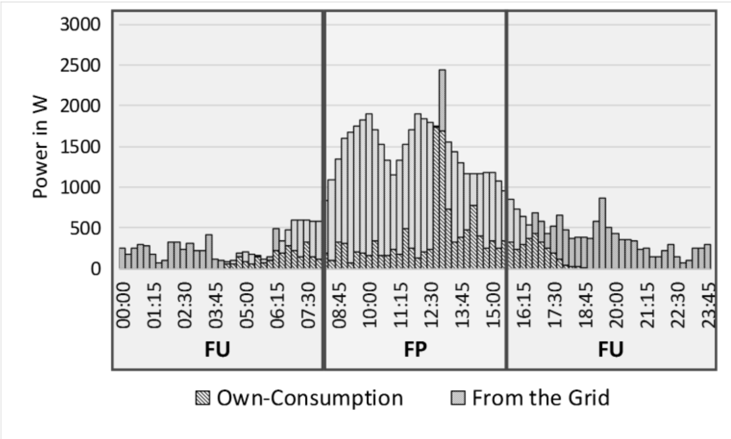

Figure 2: Two step approach for the use of household flexibilities [12].

In short, the load shifting capabilities of the flexibilities will be used primarily for increasing the PV own consumption of the FP. A secondary use is for the FU to optimise his energy trading on the liberalised electricity market. The central optimiser will have to primarily consider the needs of the FP over the needs of the FU. To ensure that the maximum of PV-energy is stored within the thermal storage (boiler, thermal mass of the building, etc.) a forecast-based approach is used. This approach facilitates forecast data of PV-generation for the current day as well as thermal energy demand (heating and warm water) and market prices. For modelling purposes these values were predefined. In the actual application during the demonstration phase of *Hybrid Grids Demo* actual forecast for PV-generation and energy demand data from previous days will be used. Basically, to estimate the financial benefit of the facilitation of flexibilities, 100 % accurate forecasts are implied.

To ensure that the maximum of PV-generation is considered, an algorithm was developed, which uses the forecast data to optimise the behaviour of the HGA. Building on the forecast data for PV and thermal energy demand, the algorithm will forecast the amount of thermal energy generated from the surplus of PV-energy and will then reserve the required capacity in the storage system. For each day the first times-step t_{First} where a sufficiently high PV-surplus is predicted and the last time-step t_{Last} are identified. Disregarding the constraint of the storage capacity the total thermal energy in between these two time-steps is calculated.

$$E_{therm_{tot}} = \sum_{t=t_{First}}^{t_{Last}} E_{A_{PV}}(t) \cdot f_{conv} - E_{DEM_{th}}(t) \tag{1}$$

$E_{therm_{tot}}$	Total thermal energy generated from the daily surplus [kWh_t]
$E_{A_{PV}}(t)$	Relevant used surplus of electrical energy for the heat generating appliance at any given time *t* [kWh_e]
f_{conv}	Conversion factor from electrical energy to thermal energy, depending on the technology used and the current surrounding parameters
$E_{DEM_{th}}(t)$	Total thermal energy demand at a given time t [kWh_t]

Since the appliance used for converting the electrical energy in thermal energy has a certain minimum electrical power, not all renewable surpluses are relevant for consideration.

$$P_{A_{PV}}(t) = \begin{cases} 0, & P_{PV}(t) - P_L(t) < f_{ON} \cdot P_{conv}(t) \\ f_{ON} \cdot P_{conv}(t), & P_{PV}(t) - P_L(t) \geq f_{ON} \cdot P_{conv}(t) \end{cases} \quad (2)$$

$P_{PV}(t)$	Current PV generation [kWe]
$P_L(t)$	Current electrical load [kWe]
f_{ON}	Factor for the partial load operation of the heat conversion unit.
$P_{conv}(t)$	Electrical power of the heat generator [kWe]

The amount of thermal energy calculated in (1) defines the reserved capacity at t_{First}.

$$E_{R_{th}}(t_{First}) = \begin{cases} 0, & E_{therm_{tot}} < 0 \\ E_{St_{MAX}}, & E_{therm_{tot}} > E_{St_{MAX}} \\ E_{therm_{tot}}, & E_{therm_{tot}} \leq E_{St_{MAX}} \end{cases} \quad (3)$$

$E_{R_{th}}(t_{First})$	Reserved storage capacity at the time-step t_{First} [kWht]
$E_{St_{MAX}}$	Maximum thermal storage capacity [kWht]

The algorithm then defines, starting at t_{First} and going back until t = 1, how much thermal capacity is available for load shifting in favour for the FU.

$$E_{F_{th}}(t) = E_{St_{MAX}} - E_{R_{th}}(t+1) + E_{DEM_{th}}(t) \quad (4)$$

$E_{F_{th}}(t)$	Free storage capacity at a given time-step t [kWht]

$E_{F_{th}}(t)$ is limited by E_{St_MAX}. That way, for any give time-step before the occurance of a relevant surplus, the system knows how much electrical energy can be converted into thermal energy. This process is important, as the algorithm focussing on low market prices (FU optimised mode) will try to cover as much of the thermal demand as possible using low market prices, as this will increase the profitability of the FU.

The algorithm to reduce the costs for energy purchase of the FU uses market price forecasts within a given forecast period t_{FC}. The number of time-steps, the market prices are available for, defines t_{FC}. During that duration the market price triggering the decision of whether the appliance for heat generation shall be switched on is calculated.

For $t_R = t$ *to* $t + t_{FC}$:

$$p_{ON} = \begin{cases} min(p_M(t_R)), & mean(p_M(t_R)) \cdot f_p \leq min(p_M(t_R)) \\ mean(p_M(t_R)) \cdot f_p, & mean(p_M(t_R)) \cdot f_p > min(p_M(t_R)) \end{cases} \quad (5)$$

p_{ON}	Price threshold for the activation of the appliance [€/kWh]
$p_M(t_R)$	Market price for electricity at a given time step t_R [€/kWh]

f_p	Factor defining how higher or lower than the average value of market prices the threshold should be

Using the threshold as well as the available thermal storage capacity, the electrical energy demand of the heat generating appliance is simulated.

$$P_{A_M}(t) = \begin{cases} 0, & E_{F_{th}}(t) < f_{ON} \cdot P_{conv}(t) \cdot f_{conv} \\ 0, & p_{ON} > p_M(t) \\ P_{conv}(t), & E_{F_{th}}(t) \geq f_{ON} \cdot P_{conv}(t) \cdot f_{conv} \ AND \ p_{ON} \leq p_M(t) \end{cases} \tag{6}$$

$P_{A_M}(t)$	Electrical power demand of the heat generating appliance, due to market prices

This approach will ensure, that if there are low prices available, the appliance will consume electricity and generate heat, which then is stored in the thermal storage.
In case that neither market prices nor PV-surplus trigger the activation of the HGA and the energy levels within the storage system drop below the levels required to keep the comfort for the FP, an emergency charging is applied, which disregards the current price or PV-situation. Also, the control algorithm ensures, that the energy levels within the storage unit are always within the borders necessary to keep the required comfort of the FP.

To estimate the economic effects of applying the two-layer approach for the HGA two different key values are used. For the FP the own-consumption rate f_{OC} is considered as basis for the estimation.

$$f_{OC} = \frac{E_{PV-dir}}{E_{PV-tot}} \tag{7}$$

f_{OC}	Own consumption rate [%]
E_{PV-dir}	Total amount of PV-generation used directly on household level [kWh_e]
E_{PV-tot}	Total amount of PV-generation [kWh_e]

For the FU the critical factor is the price at which the energy is bought at the market, as the FU's yield results basically from the difference of the market price and the energy part of the customer tariff. As such the benchmark for the economic evaluation is the weighted average of market prices at which the energy to supply the FP was bought at.

Using these two benchmarks, the basic economic effects of the flexibility use on household level can be derived.

Heating Grids

Although there are some analogies between the heating network and households, the simulation and assessment of flexibilities in the heating network has to be done differently. In heating grids for example, one or more non-electrically operated heat generators are already available, which is also the case in the demonstration area of *Hybrid Grids Demo*. By integrating an additional electricity powered heat generator (in this case a heat pump), a further coupling point between electricity and heat system can be created, through which the thermal flexibility can be utilised for the electricity system. This requires - similar to households - an integration of the heating station of the heating grid in the central optimiser located within the control centre of the electricity grid operator. As the operators of the heat and electricity are bundled within one company, flexibility provider (FP) and flexibility user (FU) are the same entity, which calls for a different business model than for household flexibility providers. Thus the goal for the heating grid is to minimise the heat generation costs and earning the additional benefit of creating flexibility options for the electricity grid. This has to be done by taking into account changings of the amount of fed in electricity at dynamic market price.

In the existing heating grid, a combined heat and power plant (CHP) generates the base load of heat and feeds electricity into the public grid receiving a subsidized feed-in tariff. As the funding period is about to end, a new operation strategy has to be developed taking into account ongoing fuel costs for CHP and market prices for electricity. The same goes for existing PV-plants, which also have subsidised feed-in tariffs stopping soon, located near the heating station of the heating grid could also deliver electricity for heat generation. Because of this initial situation, a rule-based operation strategy has to be developed to secure further economic operation. To develop suitable concepts a techno-economic simulation model was created for this part of the energy system.

Simulation model of the optimised heating generation for the heating grid

The goal of using the load shifting capability of the heating station of the heating grid is to secure lowest possible heat generation costs. Indirectly, by taking into account market prices of electricity in the rule-based operation strategy of the heat generation, benefits also occur on the electricity side.

The heating station in the heating network currently comprises the following components:

- A combined heat and power plant (CHP) with a thermal output of 398 kW_t and an electrical output of 280 kW_e.
- A biomass boiler with the capacity of 600 kW_t and an efficiency of 90%.

In order to create new flexibilities and on-site use of PV-generation, the following extensions are being considered and analysed:

- A heat pump replacing the biomass boiler with the thermal output of 600 kW_t using an onsite waste heat stream with 50°C and a seasonal performance factor of 4.
- Direct lines for connecting PV-systems with a peak power of 66 kW_e near the site with the heat pump.

The simulation model is based on the historical data of the heating demand of the grid, the PV-production, the market price for electricity, grid fees and taxes for the year 2015. Overall heating demand for the grid is 2,5 GWh_t with a maximum load of 689 kW_t. PV-production is 1.075 kWh_e/kW_p, fuel consumption of the CHP is 2,62 kWh_{gas}/kWh_e.

To ensure the lowest possible costs for heat generation, marginal generation cost of each option (type of energy generation) are set with the following equation for each time step:

$$MC_{t,i}(t) = \frac{p_{f,i}(t)}{\eta_i(t)} - p_{m,i}(t) \cdot E_{e,CHP}(t) \tag{8}$$

$MC_{t,i}(t)$	Marginal cost of heat production of option i [€/kWh]
$p_{f,i}(t)$	Price of fuel or electricity from different sources [€/kWh]
$\eta_i(t)$	Fuel efficiency [-]

$p_{m,i}(t)$	Market price for electricity (only for CHP) [€/kWh]
$E_{e,i}(t)$	Produced electrical energy (only for CHP) [kWh]

The options consider the fuel type and fuel price as well as their respective power limitations see Table 1. It should be noted that the heat pump can use electricity from different sources combined. The price of the biogas is lower than the price of natural gas. The reason for this is that the biogas is extracted from leftovers, the plant has already been written off.

Table 1 heat production options

Option	Fuel	Power limitation	Fuel price
CHP	Biogas	-Nominal power of CHP	2 ct/kWh
Biomass boiler	Biomass (wood)	-Nominal power of boiler	2,2 ct/kWh
Heat pump – CHP	Electricity from CHP	-Nominal power of heat pump -electricity produced by CHP	Opportunity cost of not fed in energy (market price)
Heat pump – PV	Electricity from PV	-Nominal power of heat pump -Electricity produced by PV	Opportunity cost of not fed in energy (market price)
Heat pump – grid	Electricity from public grid	-Nominal power of heat pump	Market price of energy, grid costs, taxes for energy related costs in grid level 5

Based on (8) and the limits in Table 1 for each time step the heat source with the lowest price is identified and used, followed by the heat source with the second lowest price and so on until heating demand is covered. It has to be stated here, that the analysis should serve as an estimation of the potential of the approach. For the simulation, 15-minute time steps were analysed, so this time span can be considered as the minimum runtime for the components. In addition, any start-up and shut-down losses are neglected, an ideal continuous control of the units is assumed.

For the analysation of the potentials of the approach a comparison between three scenarios was done. For reference purposes two scenarios were defined: (1) baseline scenario 1 represents the current power-driven strategy after the expiring promotion tariffs and (2) baseline scenario 2 shows the impact of the change in strategy to a heat-driven operation. The scenario depicting the new approach is referred to as flexbility scenario. In both baseline scenarios, the CHP delivers the thermal base load the biomass is the peak load boiler.

For the baseline scenario 1 and 2 the heating production costs can be calculated according to equation (9).

$$C_{HG,b,j} = \sum_{t=1}^{t=35,040} MC_{t,CHP,b,j}(t) \cdot E_{t,CHP,b,j}(t) + MC_{t,B,b,j}(t) \cdot E_{t,B,b,j}(t) \tag{9}$$

$C_{HG,b,j}$	Annual costs of heat generation in the baseline scenario 1 and 2 (BS) [€]
$MC_{t,CHP,b,j}(t)$	Marginal costs of thermal production via CHP (BS1+2) [€/kWh]

$E_{t,CHP,b,j}(t)$	Thermal energy produced by CHP (BS1+2) [kWh]
$MC_{t,B,b,j}(t)$	Marginal costs of thermal production via biomass (BS1+2) [€/kWh]
$E_{t,B,b,j}(t)$	Thermal energy produced by biomass (BS1+2) [kWh]

Overall costs for the flexibility scenario can be calculated with (10).

$$C_{HG,flex} = \sum_{t=1}^{t=35,040} MC_{t,CHP,f}(t) \cdot E_{t,CHP,f}(t) + MC_{t,HP,f}(t) \cdot E_{t,HP,f}(t) \quad (10)$$

$C_{HG,flex}$	Annual costs of heat generation in the flexibility scenario (FC) [€]
$MC_{t,CHP,f}(t)$	Marginal costs of thermal production via CHP in FC [€/kWh]
$E_{t,CHP,f}(t)$	Thermal energy produced by CHP in FC [kWh]
$MC_{t,HP,f}(t)$	Marginal costs of thermal production via HP in FC [€/kWh]
$E_{t,HP,f}(t)$	Thermal energy produced by HP in FC [kWh]

The annual generation of thermal energy of the individual heat generators can be determined using following equation (11).

$$E_{HG} = \sum_{t=1}^{t=35,040} E_{t,CHP}(t) + E_{t,BM}(t) + E_{t,HP,l}(t) + E_{t,HP,g}(t) \quad (11)$$

E_{HG}	Annual energy production [kWh]
$E_{t,CHP}(t)$	Thermal energy production of CHP at given time step [kWh]
$E_{t,BM}(t)$	Thermal energy production of BM at given time step [kWh]
$E_{t,HP,l}(t)$	Thermal energy production of HP with local electricity at given time step [kWh]
$E_{t,HP,l}(t)$	Thermal energy production of HP with electricity from the grid at given time step [kWh]

For the operator of the heating network, savings potentials can thus be demonstrated based on current market mechanisms by creating a coupling point between electricity and heat (heat pump). Since the FU and FP are united in one organization, the presentation of the separate benefit for individual parties is dispensed with. Likewise, due to the complex connection conditions for the authorization to be able to offer control power (secondary or tertiary), the exploitation of this market mechanism not part of the examination.

ECONOMIC EFFECTS OF THE UTILISATION OF FLEXIBILITIES

Economic Effects for Heating Devices in Households

For the estimation of the economic effects of the flexibility use, a set of different households is used. These households are described in detail in [13]. In total a set of 22 different relevant cases for the demonstration area were investigated.

Results for Single households

The results of the estimation of economic benefits are shown in Figure 3, the left-hand side shows the range of own consumption values of the different building cases, comparing the standard HGA control (bang-bang control) with the optimised control strategy. The figure clearly indicates the increase of own-consumption caused by the optimised HGA deployment. When considering all household-cases own consumption rates of 0 % can occur, but only because no PV-system is installed in these specific cases, whereas if only the cases with PV-generation are considered, the increase of own-consumption ranges from 7 % to 12 %, which correlates to an increase in own-consumption between 170 kWh/a and 600 kWh/a. To calculate the savings from that increase in own-consumption the trade-off between using more RES and selling less surplus needs to be considered. Assuming a tariff of 17.12 cent/kWh for energy taken from the grid and a tariff of approximately 5 cent/kWh the annual savings would account to € 23 to € 73.

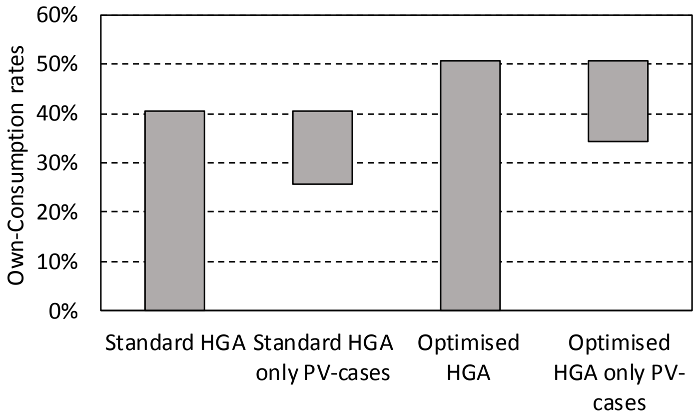

Figure 3: Range of own-consumption rates as result of the optimised HGA operation for the FP

Results for the energy supplier/grid operator

For the FU the benchmark for estimating the economic effects is the weighted average market price at which energy was bought at. Figure 4 show the results for the analysation. Again, the cases for the standard HGA control are compared with the optimised HGA control scheme and a differentiation between all cases and only the PV cases was made. The results in the figure indicate clearly, that the use of the FP's flexibility provide an economic benefit for the FU, as the weighted average of market prices drop.

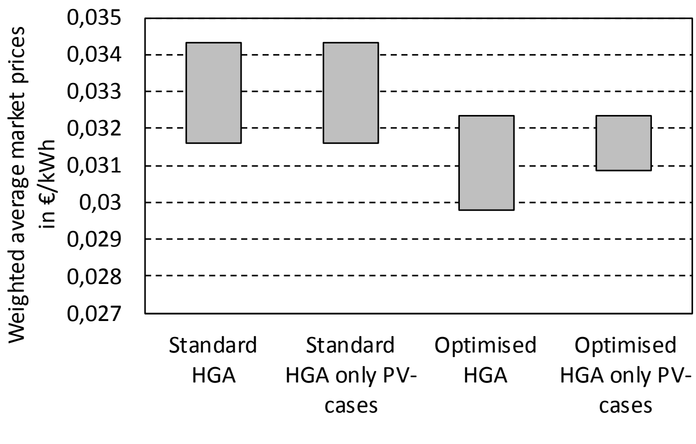

Figure 4: Range of own-consumption rates as result of the optimised HGA operation for the FP

Focusing on the two cases for the optimised HGA, it can be seen, that the household cases without PV-generation can be supplied at lower weighted average market prices (minimum: 0.0298 €/kWh) than the households with PV-generation (minimum: 0.0309 €/kWh). This difference of approximately 4 % can be easily explained. Households without PV-generation won’t need to reserve storage capacity for increasing the own-consumption, thus the flexibility can be fully used by the FU. The problem with that situation is, that the FP won’t have an incentive for providing his flexibility, as the FP doesn’t have a financial benefit.
While the advantage for the FU of reduced average market prices is obvious, it needs to be considered, that the FU will also sell less energy, due to the increased own consumption of the FP, see Figure 3.

The benchmarks displayed in this chapter indicate that there are benefits for both the FP and the FU, but the interdependencies between the two benefits in the greater scheme of the energy supply situation need to be discussed. Also, the situation that in case of the project *Hybrid Grids Demo* the FU is a non-unbundled energy supplier, combining energy supply, grid operation and energy service provision in one company, is not yet well considered within these benchmarks. As such the building on the positive results of the benchmark it will be necessary to define concrete business models in which all aspects from investment (EMS, equipment etc.) to cash flows for energy and grid operation etc. are considered over a longer period.

Economic Effects in Heating Grids

An analysation of the marginal costs of the different heat generation options shows that there are MC of heat production with a static (biomass) and dynamic (all others) characteristic. The second applies to all options which contain the dynamic electricity market price as an input parameter. Figure 5 shows the statistical distribution of the marginal heat generation costs as a box plot. As the costs overlap in a broad range, it can be assumed that different options shall apply to the chosen rule-based deployment strategy.

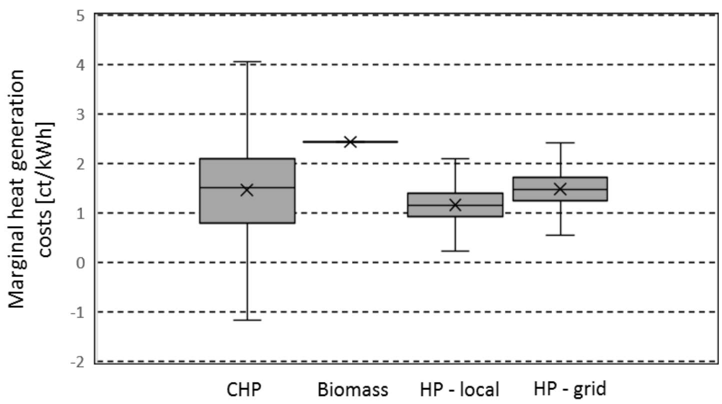

Figure 5: Statistical distribution of costs of different heat generation options

Figure 6 shows the thermal energy fed into the heating grid by the different heat generators depending on the scenario. It should be noted that in the baseline scenario 1 due to the power-operated CHP, a part of the heat produced must be considered as losses, as there is no heat demand in the network at this time. It can be seen that in the flexibility scenario, a large part of the heat pump's electricity is taken from the power grid. This is due to the fact that at high electricity prices, the CHP is mainly used as the generated electricity can be sold with profit at the market. When low electricity prices occur, the CHP can’t be operated economically, thus a use of the heat pump fed by electricity from the power grid is the cheapest option, even when considering grid fees. The locally generated PV power is used as a primarily by the heat pump, but due to the low generation capacity on site, the low share of PV-generation being used by the heat pump results.

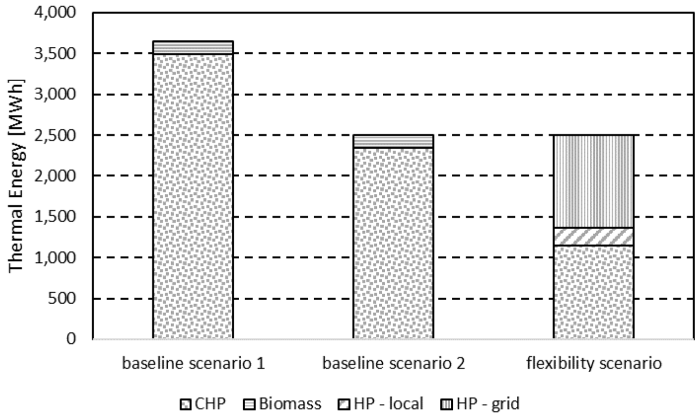

Figure 6: Statistical distribution of costs of different heat generation options

Comparing the annual costs for the heat generation of the individual scenarios, it is quickly apparent that a power-driven operation after the end of the subsidized feed-in tariff makes no sense. Figure 7 below therefore uses Baseline Scenario 2 as a reference. The annual savings in operating the Flex scenario over the heat-managed Baseline Scenario total ~39% or € 14,731.

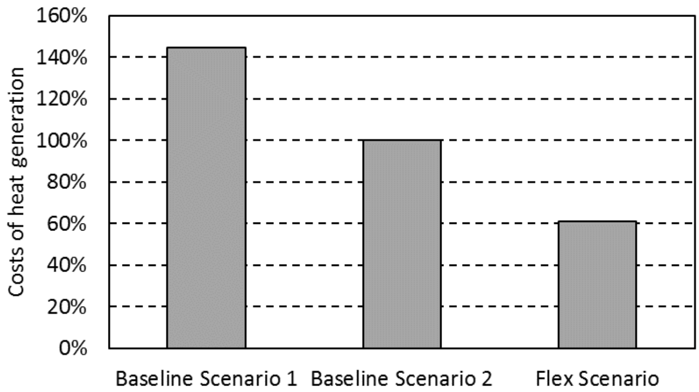

Figure 7: Comparison of heat generation costs

At this point, it should be mentioned once again that only energy-related costs and fees were taken into account when calculating the grid fees. It must therefore be ensured that the use of the heat pump does not increase the power-related network costs and that an existing grid connection at network level 5 can be used, since otherwise the green electricity provision rate must be taken into account additionally [14]. In some federal states in Austria there are also interruptible tariffs at network level 5 without the billing of power-related fees. From an economic point of view, these are an interesting option for large heat pumps in heating networks.

In the further course of the project, the analysed heat pump solution will be implemented. Up to the actual operation an application optimisation is to be developed and integrated in the central optimiser of the Hybrid Grid, which enables the selection of the heat generation taking into account electricity price and heat demand forecasts as well as real control and start-up and shutdown losses.

CONCLUSION

The energy system will in future required an increased amount of customer side flexibility. Thermal appliances in combination with thermal storage can provide such flexibilities if an incentive is given to the flexibility provider and the flexibility user.

The results on household level clearly show, that the two-layered approach for the use of household flexibility generate an economic benefit for both the flexibility provider (household) and flexibility user (local energy supplier). It needs to be considered, that in the case of the project *Hybrid Grids Demo* the FU is a not-unbundled energy supplier, which enlarges the spectrum of possibilities for the use of the flexibilities. Two benchmarks to quantify the benefits were defined, while they give a good indication on the financial feasibility of the approach a detailed analysation calls for a consideration of exact business models and their respective cash flows. Considering the FP the benchmark value *"own-consumption rate"* was defined. The simulations show, that by using the two layered approach leads to an increase of own-consumption between 7 % and 12 %, which correlates to annual savings of € 23 to € 73 through the use of the flexibilites. These numbers indicate that the system enabling the load shifting capabilities will have to follow a low-cost approach. For the FU the benchmark of *"weighted average market prices"* was introduced, describing the price at which the FU buys energy at the energy market. Applying the two-layered approach, thus using flexibilities of the FP when it isn't used for maximised own-consumption, leads to a drop of up to 13 %. The highest drops are reached for those cases where the FP doesn't have a PV-system, which is a problem, since this FP won't have a financial incentive to provide his flexibility.

This situation in combination with the limits to the benchmarks defined in this paper calls for the definition of actual business models which define exactly which costs, benefits and cashflows occur for the FP and all divisions of the FU (not unbundled energy supplier), considering the necessary technologies to enable and activate the load shifting potentials.

In the heating network there is no need to share the benefits between FP and FU due to the existing ownership structure. Rather, as low as possible heat production costs are to be strived for after the expiration of tariff subsidy for the fed-in electricity of the CHP. A potential estimation shows that the use of a heat pump in combination with an existing waste heat flow offers savings potential compared to the heat-controlled operation after the end of the tariff subsidy of 39% or € 14,731. In addition to the locally produced electricity through the CHP and PV-Systems, grid electricity at low-price times should also be used. The decision regarding the deployment strategy is made taking into account the requirements of the power grid in the central optimizer of the energy supplier/grid operator.

NOMENCLATURE

$E_{therm_{tot}}$	Total thermal energy generated from the daily surplus [kWh_t]
$E_{A_{PV}}(t)$	Relevant used surplus of electrical energy for the heat generating appliance at any given time t [kWh_e]
f_{conv}	Conversion factor from electrical energy to thermal energy, depending on the technology used and the current surrounding parameters
$E_{DEM_{th}}(t)$	Total thermal energy demand at a given time t [kWh_t]
$P_{PV}(t)$	Current PV generation [kW_e]
$P_L(t)$	Current electrical load [kW_e]
f_{ON}	Factor for the partial load operation of the heat conversion unit.
$P_{conv}(t)$	Electrical power of the heat generator [kW_e]

$E_{R_{th}}(t_{First})$	Reserved storage capacity at the time-step t_{First} [kWh_t]
$E_{St_{MAX}}$	Maximum thermal storage capacity [kWh_t]
$E_{F_{th}}(t)$	Free storage capacity at a given time-step t [kWh_t]
p_{ON}	Price threshold for the activation of the appliance [€/kWh]
$p_M(t_R)$	Market price for electricity at a given time step t_R [€/kWh]
f_p	Factor defining how higher or lower than the average value of market prices the threshold should be
$P_{A_M}(t)$	Electrical power demand of the heat generating appliance, due to market prices
f_{OC}	Own consumption rate [%]
E_{PV-dir}	Total amount of PV-generation used directly on household level [kWh_e]
E_{PV-tot}	Total amount of PV-generation [kWh_e]
$MC_{t,i}(t)$	Marginal cost of heat production of option i [€/kWh]
$p_{f,i}(t)$	Price of fuel or electricity from different sources [€/kWh]
$\eta_i(t)$	Fuel efficiency [-]
$p_{m,i}(t)$	Market price for electricity (only for CHP) [€/kWh]
$E_{e,i}(t)$	Produced electrical energy (only for CHP) [kWh]
$C_{HG,b,j}$	Annual costs of heat generation in the baseline scenario 1 and 2 (BS) [€]
$MC_{t,CHP,b,j}(t)$	Marginal costs of thermal production via CHP (BS1+2) [€/kWh]
$E_{t,CHP,b,j}(t)$	Thermal energy produced by CHP (BS1+2) [kWh]
$MC_{t,B,b,j}(t)$	Marginal costs of thermal production via biomass (BS1+2) [€/kWh]
$E_{t,B,b,j}(t)$	Thermal energy produced by biomass (BS1+2) [kWh]
$C_{HG,flex}$	Annual costs of heat generation in the flexibility scenario (FC) [€]
$MC_{t,CHP,f}(t)$	Marginal costs of thermal production via CHP in FC [€/kWh]
$E_{t,CHP,f}(t)$	Thermal energy produced by CHP in FC [kWh]
$MC_{t,HP,f}(t)$	Marginal costs of thermal production via HP in FC [€/kWh]
$E_{t,HP,f}(t)$	Thermal energy produced by HP in FC [kWh]
E_{HG}	Annual energy production [kWh]
$E_{t,CHP}(t)$	Thermal energy production of CHP at given time step [kWh]
$E_{t,BM}(t)$	Thermal energy production of BM at given time step [kWh]
$E_{t,HP,l}(t)$	Thermal energy production of HP with local electricity at given time step [kWh]
$E_{t,HP,l}(t)$	Thermal energy production of HP with electricity from the grid at given time step [kWh]

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