fit4power2heat: Work Package 4

Results of the WP4 and deliverable D4.1
(Bericht über bewertete Konzepte und geeignete Geschäftsmodelle)

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Content

1 Introduction

Deliverable 4.1 “Report on evaluated concepts and business models” presents the results from the work package 4 “Evaluation and analysis of business models”.

Chapter 2 contains a techno-economic evaluation of the different use cases defined in deliverable D3.1. They are simulated by means of an optimization model and the output is assessed for each use case. The results show the optimal operation strategy for the biomass boiler, heat pump and storage, as well and the optimal bidding strategy for the heat pump. Based on these results, the annual specific electricity and heating costs, as well as the annual heat generation costs are calculated, in order to evaluate the cost reduction and increase of revenues obtained with the implementation of the heat pump.

The second section of chapter 2 focuses on the heat pump pool concept. Heat pumps can usually only fulfill the prequalification criteria for the balancing market if they participate in a pool. Therefore, the costs associated with the heat pump pool are presented. Besides, a description of the implementation of the heat pump pool in the optimization model, as well as the advantages and disadvantages associated with the pooling are described.

Chapter 3 focuses on the development of the business models. The first section presents the inputs required by the tool used for the economic assessment, such as the investment costs, subsidies, operation and maintenance costs and grid costs. Besides, the economic key figures calculated by the tool are defined, such as the internal rate of return (IRR), the return on capital employed (ROCE) and the earnings before interest and taxes (EBIT). Considering the results, two business models are proposed, based on the business model Canvas. Additionally, the risk associated to the investment is determined with a sensitivity analysis, which evaluates the influence of future market developments on the proposed business models.

2 Techno-economic assessment of the use cases (Task 4.1)

This chapter introduces a techno-economic assessment of the use cases presented in deliverable D3.1, chapter "4.3 Use case development". The use cases are simulated under state-of-the-art and future boundary conditions by means of an operational optimization model (for further information refer to deliverable D3.1, chapter "5 Optimization model").

2.1 Optimal heat plant operation and bidding strategy

The output data from the optimization model are assessed techno-economically for each use case. The results present the optimal operation strategy for the biomass boiler, heat pump and storage, as well as the optimal bidding strategy for the heat pump.

The overall operation of the heat plants in the network is influenced by the source of the heat pump. As described in deliverable D3.1 (chapter "4.3 Use case development"), two different sources are considered: flue gas and sewage water. They require a different hydraulic integration for the heat pump (explained in deliverable D3.1, chapter "4.3.6.1 Optimal heat pump integration"), which affects its interaction with the biomass boiler.

2.1.1 Results for use cases with flue gas as a source for the heat pump

When the flue gas is considered as a source, the operation of the heat pump and the biomass boiler is interdependent. This means that the biomass boiler needs to be active in order to operate the heat pump. If the electricity prices are attractive enough, the heat pump always contributes to the heat generation, which requires the operation of the biomass boiler as well. In this case the biomass boiler runs mostly driven by the electricity market.

In those periods with low heat demand and attractive electricity prices, meaning cheap prices in the day-ahead spot market and high revenues in the balancing market, the excess heat generated is charged into the thermal storage. The storage provides flexibility to the system and it is used frequently to satisfy the heat demand when neither the biomass boiler nor the heat pump are operating due to high electricity prices.

As an example, Figure 1 shows the operation of the biomass boiler, heat pump and storage for one week in winter, on a 15 minutes basis, for the use case *B3-FG* (described in deliverable D3.1, chapter "4.3 Use case development", table 8). In this use case, the heat pump is operating on the day-ahead spot market and offering its flexibility on the balancing market for aFRR. The "low" bidding strategy is used, meaning the heat pump gets low energy prices but has a higher probability to be called by the market. The results can be generalized to all use cases using flue gas. The optimization model chooses to run the biomass boiler and the heat pump simultaneously, in order to take advantage of the efficiency increase provided by the heat pump to the overall system.

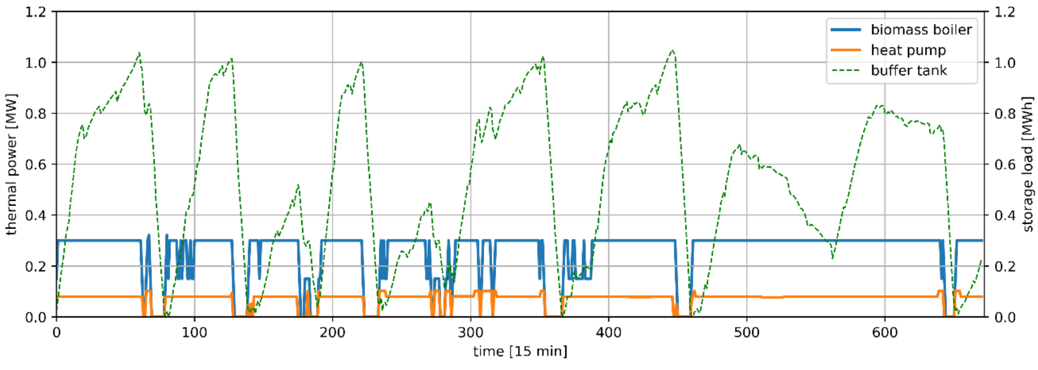

Figure 1: optimal operation of the biomass boiler, heat plant and storage for 1 week (15-minutes basis time step). Use case: B3-FG.

Figure 2 shows the variation of the electricity prices for the same week in the day-ahead spot market and the balancing market, including balancing power and energy (both positive and negative). When the electricity prices in the day-ahead spot market increase, the heat pump does not operate. Since the system cannot benefit from the efficiency increase provided by the heat pump, running the biomass boiler becomes unattractive, which forces the discharge of the storage if available. On the contrary, when the prices in the day-ahead spot market decrease, the heat pump becomes the cheapest heat supplier, charging the storage if the heat demand is already covered.

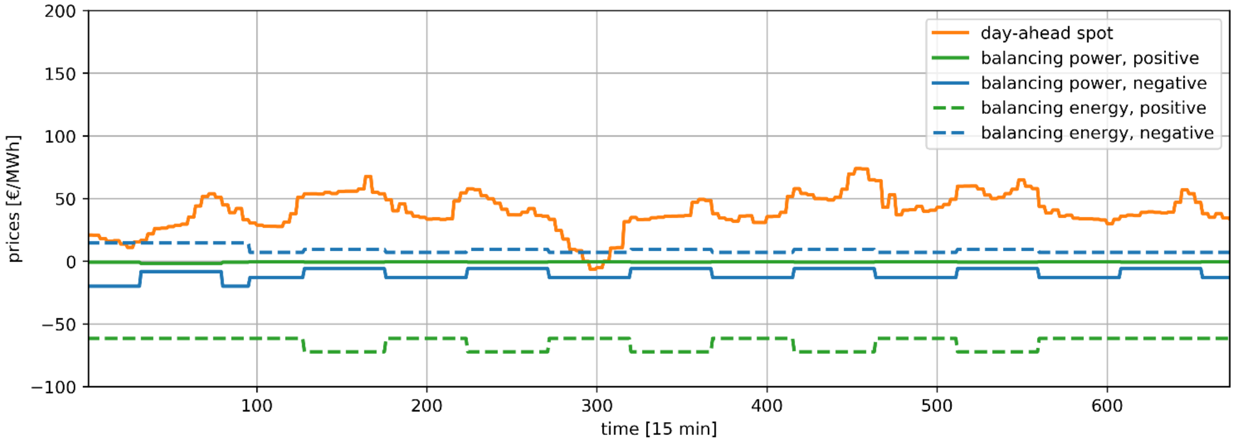

Figure 2: electricity prices in the day-ahead spot market and balancing market (1 week in winter, 2017)

The optimal heat pump bidding strategy is associated with the “low” bidding strategy. It considers low energy prices (55 €/MWh for positive and -9 €/MWh for negative balancing energy in average) and high call probabilities (77% for positive and 87% for negative balancing energy in average). The heat pump buys 50% of the energy in the day-ahead spot market and offers 50% of its capacity for negative balancing energy for aFRR (Figure 3). This means that the heat pump normally runs at 50% of its capacity, which corresponds to its minimum load, and increases the capacity to its maximum value if there is a market call. Due to the high call probabilities in the low merit order position, the heat pump is frequently activated and gets additional heat for very low prices or even gets paid by the balancing market for consuming the energy.

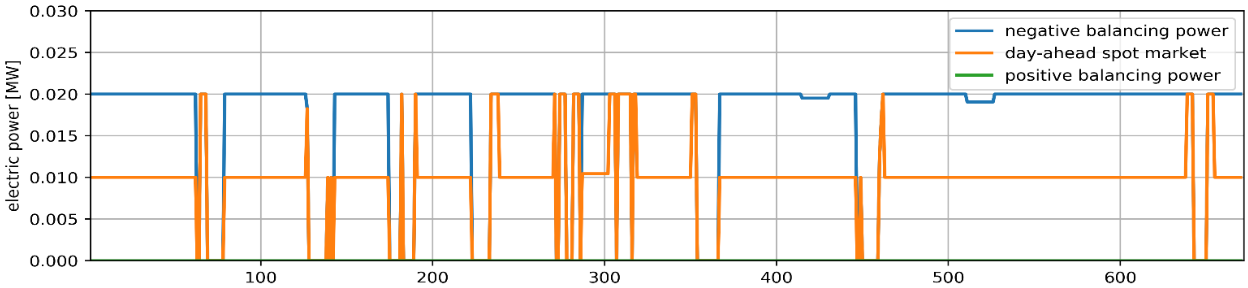

Figure 3: “low” bidding strategy for the heat pump (1 week). Use case: B3.1-SW.

On the contrary, the “high” bidding strategy considers high energy prices (4.446 €/MWh for positive and 3.271 €/MWh for negative balancing energy in average) and low call probabilities (0,1% for positive and 5% for negative balancing energy in average). As shown in Figure 5, the heat pump buys 100% of the energy in the day-ahead spot market and offers 50% of its capacity for positive balancing energy. This means that the heat pump normally runs at 100% of its capacity and reduces the capacity 50%, which corresponds to its minimum load, if there is a market call. The power is lower when there is a balancing energy call, which leads to a reduction of the grid costs. In overall, however, the “high” bidding strategy is associated with higher electricity costs than the “low” bidding strategy, due to the less frequent market calls.

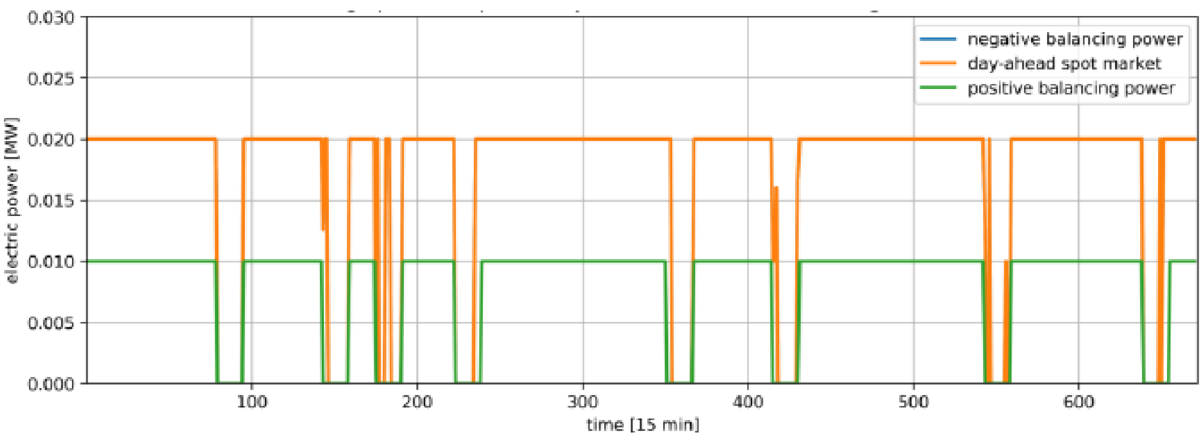

Figure 4: “high” bidding strategy for the heat pump (1 week). Use case: B3.1-SW.

2.1.2 Results for use cases with sewage water as a source for the heat pump

On the other hand, when the sewage water is considered as a source for the heat pump, the operation of the heat pump and the biomass boiler is not linked as in the previous case. Figure 5 shows the heat supplied by the heat plants and the storage in the use case B3.1-SW (described in deliverable D3.1, chapter “4.3 Use case development”, table 8) for 1 week. This is again the use case, where the heat pump operates on the day-ahead spot market and offers aFRR with the “low” bidding strategy. The result is extensible to all use cases considering sewage water. The heat pump runs as a baseload since it is the cheapest supplier and if needed, the biomass boiler covers the remaining heat demand. Therefore, the biomass boiler runs mostly driven by the heat requirements in the network. The storage provides flexibility to the system, but it is used less frequently due to the detached operation of the heat pump and the biomass boiler.

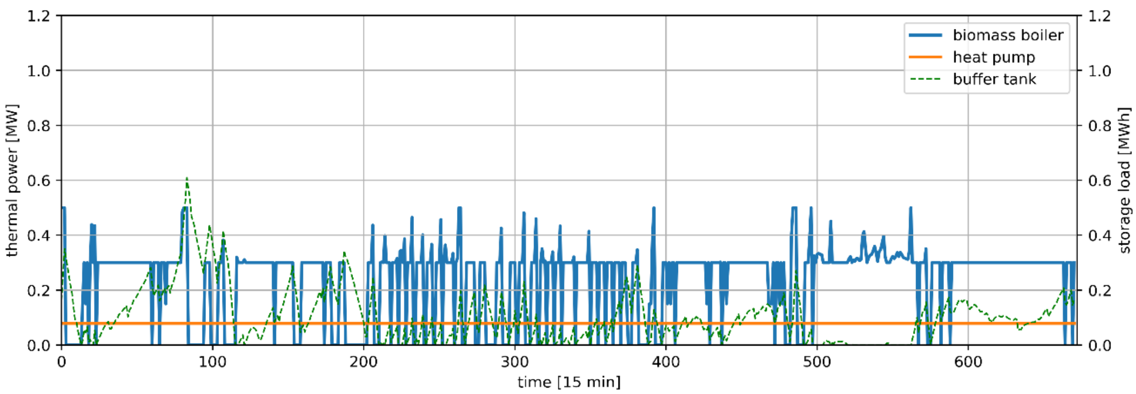

Figure 5: optimal operation of the biomass boiler, heat plant and storage for 1 week (15-minutes basis time step). Use case: B3.1-SW.

As it occurs for the use cases with flue gas, the optimal bidding strategy recommends to buy 50% of the energy in the day-ahead spot market and offer 50% of the capacity for negative balancing energy for aFRR (Figure 6). Therefore, the heat pump runs at 50% of its capacity, which corresponds to the minimum load, and increases the capacity to its maximum value if there is a market call. The heat pump takes advantage of the possibility to supply heat at very low cost or even get paid for consuming the energy by the balancing market.

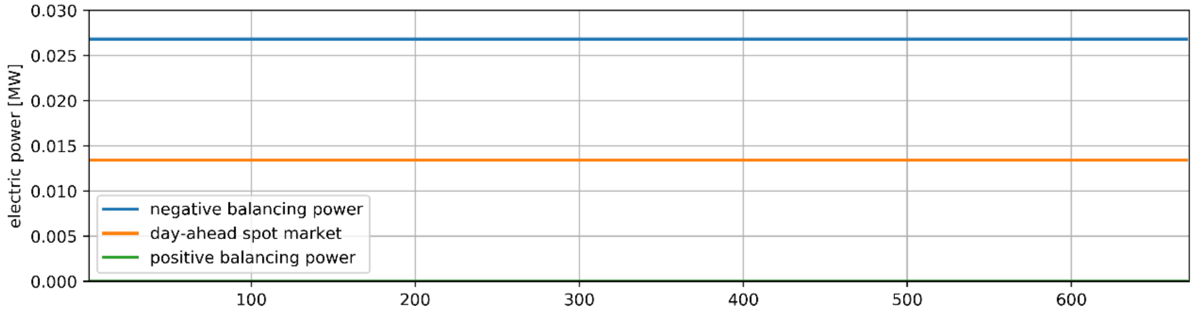

Figure 6: optimal bidding strategy for the heat pump (1 week). Use case: B3.1-SW.

2.2 Heat generation costs

The output from the simulations is evaluated in the economic module in order to estimate the benefits of installing a heat pump in the use cases assessed. The following indicators are given as a result of the simulations:

- Optimal operational costs for biomass boilers and heat pumps
- Total heat generation of the heat suppliers
- Load profiles for the biomass boiler, heat pump and the thermal storage
- Full-load operation time of the biomass boilers and heat pumps.
- The energy bought in the day-ahead market by the heat pump and the positive/negative power offered by the heat pump in the balancing market.
- Revenues from the heat sale

Table 1 includes some of the most relevant simulation results for the thermal network and the electricity grid. These values are implemented in the calculation of the specific electricity costs, specific heat generation costs and total heat generation costs.

Table 1: annual operational hours and costs in the thermal and electricity networks

Concept	Use case	Thermal network			Electricity grid			
		Full load op. time biomass boiler 1 [h]	Full load op. time biomass boiler 2 [h]	Heat generation costs boilers	Full-load operation time (reserved capacity included) (h)	Electricity costs (day ahead or flat tariff) (€/year)	Grid costs (€/year)	Balancing revenues (€/year)
A Flue gas	A-baseline	2201	1263	156005	0	0	0	0
	A1	1914	857	131128	4523	13362	12312	0
	A2	1908	833	130685	4668	6661	12607	0
	A3	1948	815	133469	5212	4220	9330	-127
	A4	1907	816	130532	4802	6947	12757	792
	A5	1907	823	130623	4824	6893	12695	1271
	A6	1911	830	130783	4684	6714	12573	192
	A7	1907	830	130599	4699	6744	12650	161
B Flue gas	B-baseline	3272	0	45212	0	0	0	0
	B1-FG	2521	0	31476	3681	5228	5457	0
	B2-FG	2434	0	30542	4109	2472	5876	0
	B3-FG	2507	0	31512	4550	1642	4491	3
	B4-FG	2439	0	30561	4231	2558	5847	306
	B5-FG	2441	0	30623	4290	2552	5843	506
	B6-FG	2446	0	30656	4162	2465	5820	53
	B7-FG	2430	0	30506	4206	2515	5893	48
B Sewage water (1)	B-baseline	3272	0	45212	0	0	0	0
	B1.1-SW	2521	0	31476	2742	5228	5854	0
	B2.1-SW	1637	0	22524	8012	7115	12771	0
	B3.1-SW	1832	0	25152	8730	4225	8494	-197
	B4.1-SW	1635	0	22505	8445	7293	12765	839
	B5.1-SW	1697	0	23354	8485	7021	12380	1292
	B6.1-SW	1629	0	22443	8301	7251	12818	209
	B7.1-SW	1626	0	22387	8235	7222	12841	157
B Sewage water (2)	B-baseline	3272	0	45212	0	0	0	0
	B1.2-SW	3267	0	44773	13	38	3839	0
	B2.2-SW	643	0	8886	6443	10884	20728	0
	B3.2-SW	783	0	10756	7569	7132	14601	-274
	B4.2-SW	658	0	9086	7289	11181	20545	1469
	B5.2-SW	747	0	10304	7521	10900	20040	2637
	B6.2-SW	636	0	8783	6946	11111	20748	353
	B7.2-SW	634	0	8769	6783	11023	20781	273
C Flue gas	C-baseline	4432	0	61136	0	0	0	0
	C1	3413	0	41938	4996	7097	6744	0
	C2	3335	0	41230	5377	3543	7116	0
	C3	3423	0	42510	5939	2355	5390	-44
	C4	3334	0	41170	5569	3671	7118	378
	C5	3344	0	41313	5635	3646	7076	639
	C6	3350	0	41337	5447	3554	7046	89
	C7	3338	0	41246	5465	3572	7102	76

Considering the simulation results, a calculation of the annual specific electricity costs of the heat pumps is done. The specific electricity price (in €/MWh or cent/kWh) is calculated dividing the annual electricity costs by the annual energy consumption of the heat pump. The annual electricity costs are determined as follows:

  Annual energy cost
+ Annual grid costs
+ Grid costs for grid connection point
- Revenues (balancing market)

= Annual electricity costs

Figure 7 shows the specific electricity prices for the use cases with heat pump in concepts A, B and C. The values from 1 to 7 in the X-axis are the indices of each use case, which represent different combinations of electricity markets (as explained below). For further details about the use case characterization refer to deliverable D3.1, chapter “4.3 Use case development”, table 8.

- Concept A includes the use cases A1, A2, A3, A4, A5, A6, A7. Flue gas is considered as a source for the heat pump (224 kW_{th}).
- Concept B-FG includes the use cases B1-FG, B2-FG, B3-FG, B4-FG, B5-FG, B6-FG, B7-FG. Flue gas is considered as a source for the heat pump (102 kW_{th}).
- Concept B1-SW, includes use cases B1.1-SW, B2.1-SW, B3.1-SW, B4.1-SW, B5.1-SW, B6.1-SW, B7.1-SW. Sewage water is considered as a source for the heat pump (102 kW_{th}).
- Concept B2-SW, includes use cases B1.2-SW, B2.2-SW, B3.2-SW, B4.2-SW, B5.2-SW, B6.2-SW, B7.2-SW. Sewage water is considered as a source for the heat pump (204 kW_{th}).
- Concept C includes use cases C1, C2, C3, C4, C5, C6, C7. Flue gas is considered as a source for the heat pump (102 kW_{th}).

The specific electricity costs range between 6,9 cent/kWh for the use cases “B3.1-SW” and “B3.2-SW” and 15 cent/kWh for the use case “B1.1-SW”. The high costs linked to “B1.2-SW” are neglected from the comparison (around 570 cent/kWh), which are achieved due to the almost neglectable number of operational hours. In this case the heat pump operates with a flat electricity tariff (67 €/MWh), which explains the high electricity costs associated to its operation.

In overall the use cases with sewage water as a source present the lowest specific electricity costs for the market combinations 2 to 7, due to the high amount of full load operation hours of the heat pumps. According to the calculations, the average full-load operation hours, including the reserved capacity for the balancing market, amounts to 7564h/year for the use case “B1.SW” and 6081 h/year for the use case “B2.SW”.

In all use cases the cheapest electricity prices are presented for the electricity market combination 3, which considers the day-ahead market and the balancing product aFRR, with a low position in the merit order. This means that the participation in the secondary balancing market, considering low energy prices (55 €/MWh for positive and -9 €/MWh for negative balancing energy in average) and a high call probability (77% for positive and 87% for negative balancing energy in average) reduces the specific electricity prices. A high call probability ensures that the heat pump is activated frequently. Therefore, despite the low revenues due to cheap energy prices (in average 128€/year), reducing the grid costs associated with negative balancing energy (in average by 20% compared to the average grid costs in the other market combinations) leads to cost savings.

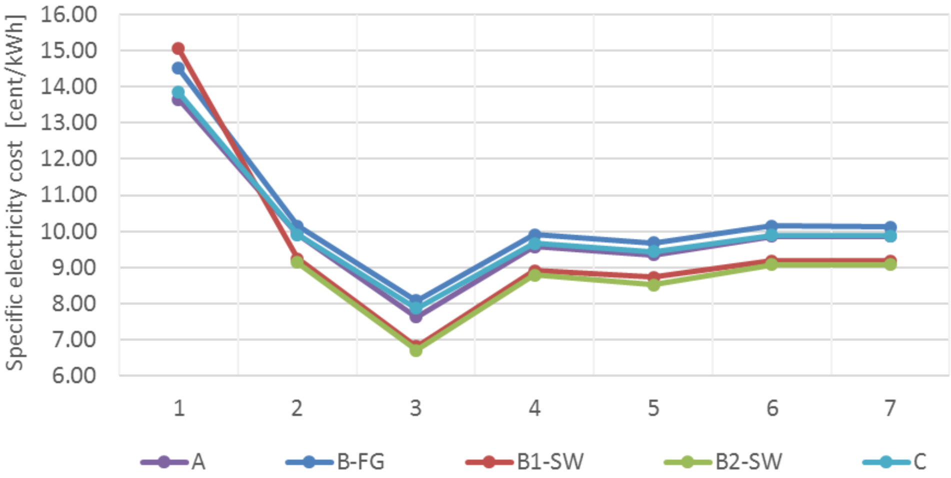

Figure 7: annual average specific electricity cost for each use case

Figure 8 shows the annual specific heat generation costs of the heat pump and the biomass boilers in all use cases (no investment or O&M costs are considered). These costs represent the relation between the biomass or electricity price considered and the heat production of the biomass boiler or heat pump. The biomass price is provided by *ENGIE Austria GmbH* (24,90 €/$MW_{produced}$) and the electricity prices are based on energy and power prices published by the Austrian Power Grid (APG) for the year 2017 (presented in deliverable D3.1, chapter "4.4 Definition of state-of-the-art and future scenarios", table 12).

According to the calculation, the specific heat generation costs of the biomass boilers range between 25,7 €/MWh and 28,3 €/MWh, while the specific heat generation costs for the heat pumps range between 14,15 €/MWh and 39,62 €/MWh. The market combination 1, which considers a flat electricity tariff (67 €/MWh), is not interesting for the heat pump since the specific heat generation costs are above the specific heat generation costs for the biomass boiler. However, the market combinations 2 to 7, where the electricity is bought on the spot market, present lower specific generation costs for the heat pump. The lowest values are associated to the use case "A3", where the day-ahead and the secondary balancing market are considered. This is explained by the fact that this use case considers low electricity prices and a high call probability which reduces the overall electricity costs.

The marginal price of electricity costs including grid costs is 13,09 cent/kWh, which equals the specific heat generation costs of the heat pump and the biomass boiler.

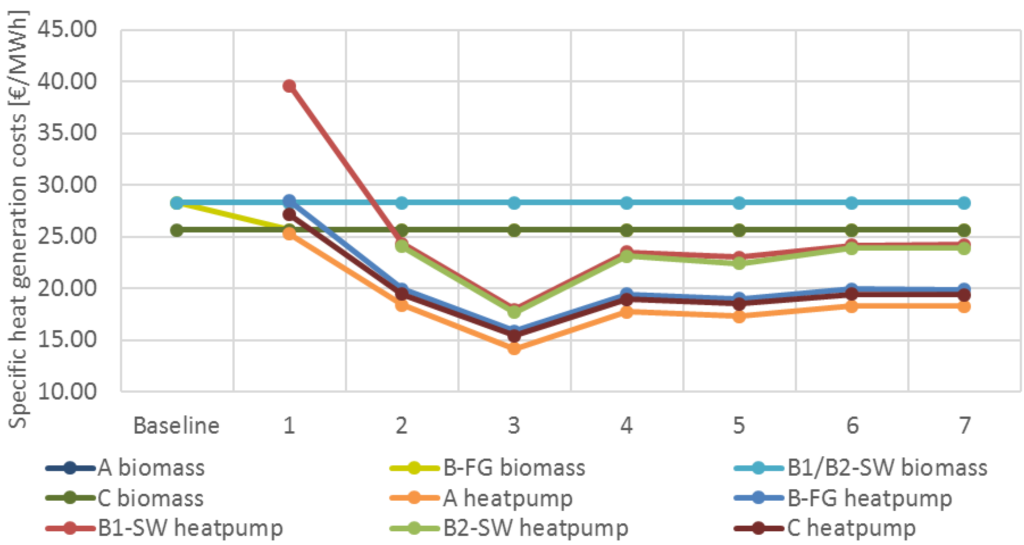

Figure 8: annual average specific heat generation costs for each use case

In order to get a better picture of the benefit of integrating a heat pump, the heat generation costs of the overall system are calculated for all use cases (the investment and O&M costs are excluded). According to the results, an optimization of the operation leads to a reduction in the heat generation costs of the network. The optimal operation of the biomass boilers, heat pump and thermal storage allows an efficient energy management. This results in a reduction of the full-load operational hours of the biomass boilers and therefore, biomass expenditure, which decreases the heat generation costs associated to the boiler. Additionally, reducing the activity of the boilers has a positive effect in the maintenance of those units reaching the end of their lifetime. Besides, an optimized heat pump strategy ensures the reduction of the overall electricity costs. This is due to the fact that the heat pump participation in the balancing markets provides revenues, as well as a reduction in the grid costs. The calculation of the heat generation costs is based on the values included in Table 1, which shows the full-load operation time of the biomass boilers, the heat generations costs associated to the boilers, as well as the electricity costs, grid costs and balancing revenues on an annual basis.

The variation in the heat generation costs for those use cases with flue gas as a source for the heat pump is presented in Figure 9, Figure 10 and Figure 11. The reduction for concept A, B and C amounts up to 5,68 %, 16,74% and 17,71 % respectively. The market combination which has the best potential for offering higher reductions is the day-ahead market in combination with the secondary balancing market ("Secondary low" in Figure 9, Figure 10 and Figure 11). This variation considers a low position in the merit order, with low prices and high probabilities to be called. Therefore, the heat pump offers negative balancing energy frequently, which also leads to a reduction in the grid costs. In all use cases except for the flat tariff in concept A, the heat generation costs can be reduced in comparison to the baseline, where no heat pump is installed.

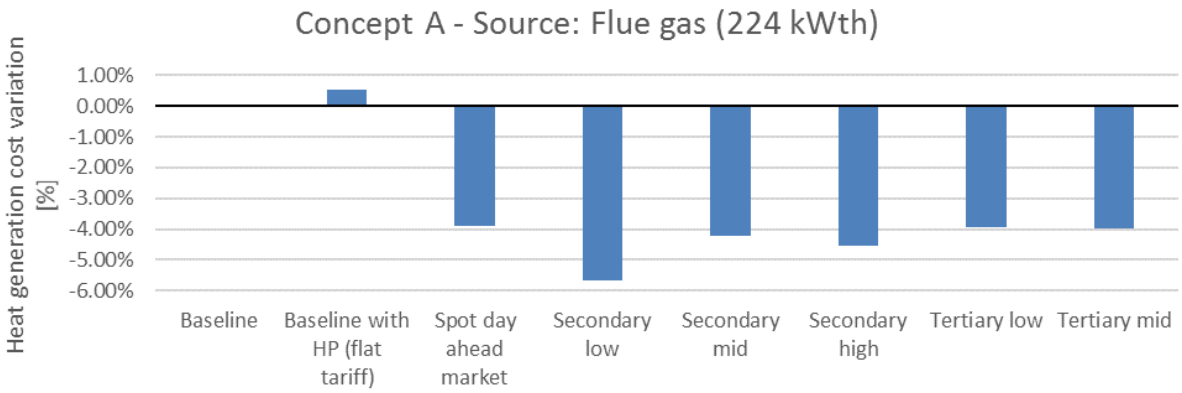

Figure 9: variation in the annual heat generation costs for concept A

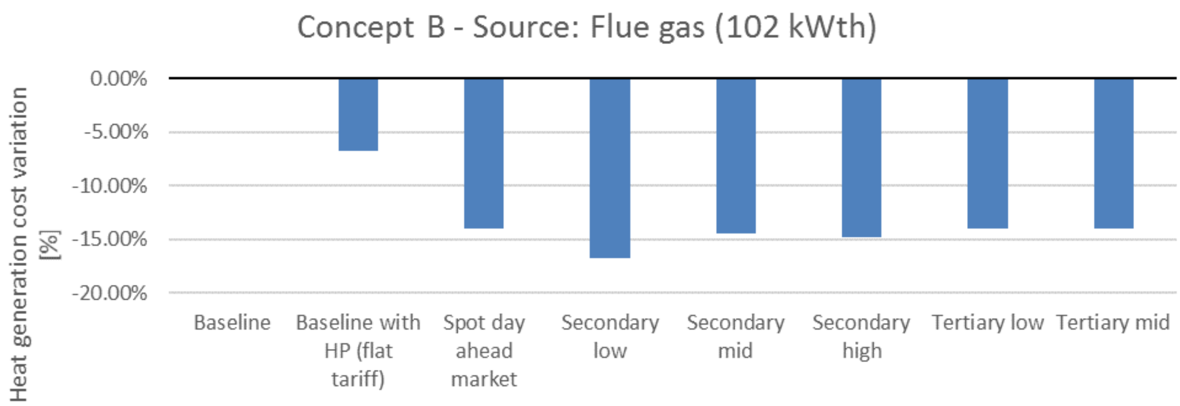

Figure 10: variation in the annual heat generation costs for concept B

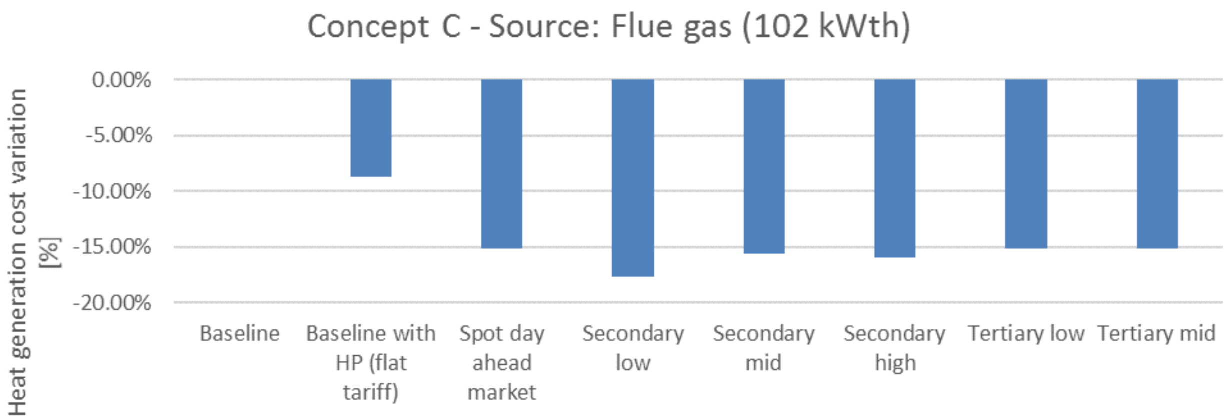

Figure 11: variation in the annual heat generation costs for concept C

Figure 12 shows the variation in heat generation costs for the use cases which consider sewage water as a source for the heat pump. The reduction in heat generation costs amounts up to 15,80% for the case with the small heat pump (102 kW_{th}) and 27,54% for the case with the large heat pump (204 kW_{th}). The reduction that can be achieved is higher in comparison with the use cases with flue gas. This can be explained by the fact the operation of the heat pump and biomass boiler is not coupled, since the heat pump does not use flue gas a source. Therefore, the integration of the heat pump leads to a higher reduction in the full-load operation hours of the biomass boilers, which results in a higher reduction of the fuel costs. The reduced operation hours of the biomass boiler are covered by the heat pump, which runs more frequently than in the use cases with flue gas as a source. This operation enables the heat pump to participate more frequently in the balancing markets, increasing the revenues and the cost savings due to the reduction in grid costs.

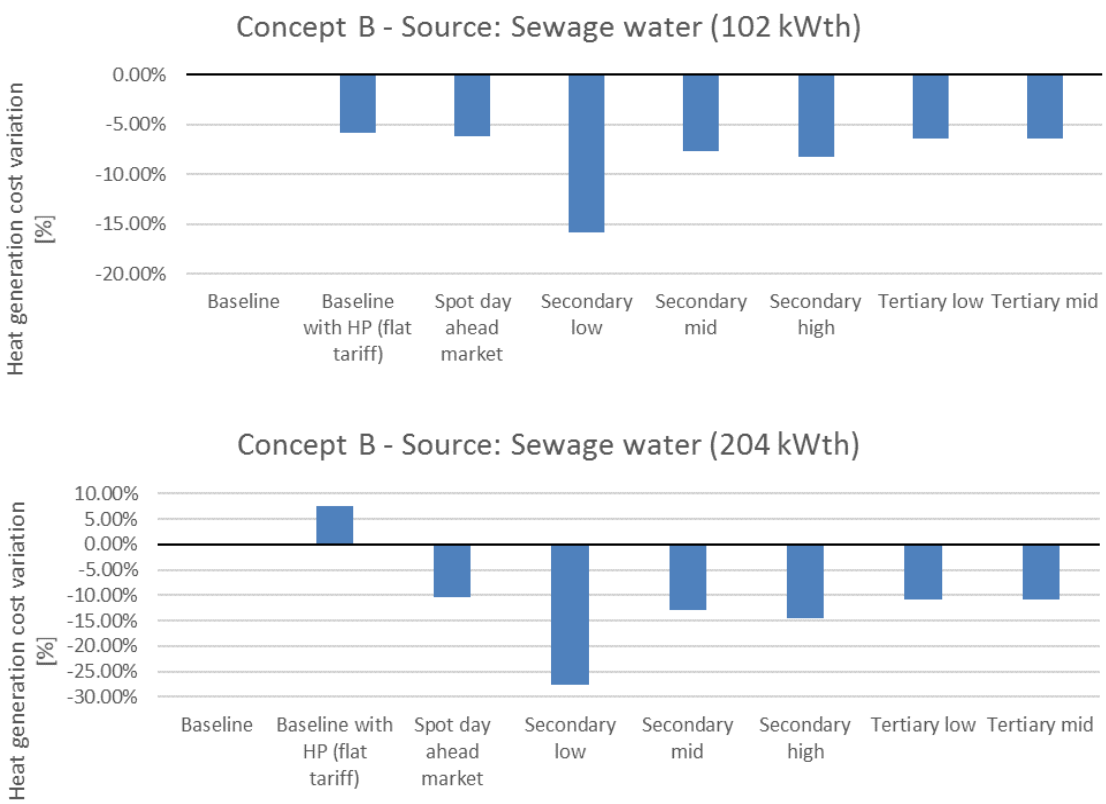

Figure 12: variation in the annual heat generation costs for the use cases with sewage water as a source for the heat pump

2.3 Heat pump pool

The heat pumps are simulated individually for each use case. However, in order to participate in the electricity markets, they usually must be part of a pool. The following chapters present the electricity market conditions which make the pooling necessary and explains the modelling approach adopted for the heat pump pool in the project *fit4power2heat*. Additionally, the advantages and disadvantages of considering the heat pump within a pool are analyzed.

2.3.1 Reasons for heat pump pooling

As described in Deliverable D2.1, heat pumps usually have to be part of a pool, in order to participate in the electricity markets. The first reason for this is the minimum capacity they have to offer in the markets. For the EPEX Spot markets, both day-ahead and intraday, the minimal trade-volume is 0.1 MW [1]. For the balancing markets, the minimum bid-size for mFRR and aFRR is currently 5 MW, for FCR it is 1 MW [2] . Since the heat pumps considered in the technical solutions presented in the project *fit4power2heat* are all smaller than 100 kW_{el}, they need to be part of a bigger pool to participate in all market segments.

The other critical market condition which often requires pooling, is the product length. For aFRR and mFRR, this product length is 4 hours. FCR, which was not considered in this project, still has weekly auctions with product length of 168 hours. However, this will likely change to daily auctions with 24-hour products in 2019 [3]. If one plant is not able to provide flexibility for the full duration of a product on its own, this could also be solved by a pooling-approach, where the product length is split between several plants. However, this was not necessary in the project *fit4power2heat*. Since there was a thermal storage available in all analyzed grids and the biomass boilers could also act as back-ups, each heat pump could individually provide the full 4h balancing products.

Beside reaching the minimum bid-size and product length to participate in the market, the pooling is also necessary to provide back-up, in case of unavailability of one of the plants. For big power plants, APG currently requires n-1 security, meaning the back-up needs to be big enough to cover the outage of the biggest plant. However, this regulation was made for big, conventional power plants. For smaller ones, there is currently no fixed rule, but it is likely that more back-up would be necessary for a pool. In the present feasibility study the back-up provision was neglected.

2.3.2 Heat pump pooling costs

When participating in the short-term electricity markets, several cost factors must be considered. Firstly, there are costs for the IT-infrastructure. For the day-ahead spot market the communication interface could be unidirectional, but for participating in the balancing markets, bidirectional communication is necessary. Furthermore, the personnel costs for providing balancing services are very high, since it is required to have a 24h-service person available. Due to those high costs for the IT-infrastructure and the operation, it would not be economically feasible to participate in the balancing markets with just a few heat pumps or power-plants. In the project hybrid-VPP4DSO [4] it was found that the minimum size of a pool for an economic market participation for mFRR is 15-20 MW.

Therefore, it was decided for the project *fit4power2heat* not to create an own pool and trade in the markets directly, but to create a sub-pool of the heat pumps, which then participates in an already existing pool. There are several independent aggregators in Austria who offer small power-plants and loads the service of a pool-provider. They usually agree on a revenue split with the flexibility provider to cover their costs. Furthermore, there can be onetime costs for installing the necessary communication infrastructure. The aggregators usually require a minimum size of the plant to participate in the pooling. Additionally, they usually require each participant to be able to provide the full 4h balancing product length by themselves. In the scope of the project *fit4power2heat*, the conditions and costs for participating in the pooling were requested from two different aggregators, next-kraftwerke [5] and A1 Telekom Austria AG [6].

For next-kraftwerke, the minimum size of a plant to participate in their pool is 150 kW electric. The costs and revenues are dependent on the size and on the specific technical solution. The installation of their communication infrastructure is between 800 € and 5.000 €. For their pooling-service, next-kraftwerke receives between 30%-50% of the market revenues from each customer.

The second offer was from A1 Telekom Austria AG. Their installation costs are 450 €; the revenue split between the aggregator and the plant operator is 30% to 70%. Since this is the more attractive offer, both with regards to the system costs and the revenue split, it was selected for the calculations within the project *fit4power2heat*.

2.3.3 Implementation of the heat pump pooling concept in the optimization model

In the optimization model, each thermal network was simulated independently, thus portfolio effects were neglected. In order to scale the results from one grid to the whole sub-pool, the revenues and costs can simply be added up. The reason why this is possible, is that each heating grid is able to provide the full 4-hour product length on its own, as mentioned in the previous chapter.

Although there is no official minimum size to participate in the A1 pool, it is likely that they have similar requirements to next-kraftwerke (>150 kW). The heat pumps considered in the project *fit4power2heat* are all below 150 kW_{el}, which means they could not participate in the pool individually under current conditions. However, when offering several heat pumps in an aggregated sub-pool, they could reach the required minimum size. Furthermore, there is current research going on, to facilitate the integration of even smaller units into the balancing market. For example, in the project Flex+ [7], heat pumps from household customers should participate in the balancing market. Therefore, the minimum size for the balancing markets was not considered in the optimization model.

Beside the minimum bid-size and the product length, there are also other technical requirements to participate in the balancing market, like the reaction times and ramp. Therefore, the following technical parameters were requested from ENGIE Kältetechnik for the analyzed heat pumps:

- Minimal runtime: 9 minutes
- Minimal shutdown period: 1 minute
- Maximum number of operation cycles: 6 per hour
- Turn-on time: 3 minutes
- Turn-off time: 3 minutes.

Those specifications are compared to the technical requirements for the balancing market (see Deliverable D2.1). The duration to switch the heat pump on and off shows that it is fast enough to participate both in the secondary and in the tertiary market. However, the maximum switching-cycles and minimum on-time could not be guaranteed, especially for aFRR, if the heat pump offered its full capacity on the market. If the heat pumps are switched more often than allowed in their specifications, this could have negative impacts on their life-time. Therefore, no full on-/off-cycles are allowed for the balancing market in the optimization model. The heat pumps can only offer balancing energy during times when they are already turned on and operating at the day-ahead spot market. When they are called by the market they only have to modulate their power. Therefore, the heat pumps never exceed the maximum switching-cycles of 6 per hour and always fulfill the minimum runtimes and shutdown periods.

Another solution for this issue would be a sub-pool. The sub-pool would only offer part of its capacity to the balancing market and be operated in a way that the heat pumps would take turns in being switched on/off. This operation strategy would ensure that none of them exceeds their maximum switching cycles.

2.3.4 Advantages and disadvantages of the heat pump pooling

In general, considering a heat pump pool as part of the heat production portfolio has several advantages: the heat pumps increase the capacity of the heating grid, which can delay the investment into a new biomass-boiler. They can increase the lifetime of an existing biomass-boiler by decreasing its run-time. Furthermore, the heat pumps can increase the efficiency of the heating grid, when using flue gas as a source. Alternatively, an external, otherwise unused heat source like sewage water can be utilized with a heat pump.

Another benefit of using heat pumps in district heating grids, is the decreased risk for the grid operator. If the only heating source would be e.g. biomass, the feasibility of the system is very dependent on the current biomass price. However, with the heat pump, a part of the heat is provided through electricity, which means they are not dependent on only one technology.

The heat pumps provide an ideal coupling point between the heating and electricity system. The storage available in the heating system, can thus also be used for the electricity grid. When the heat pump does not act independently, but becomes part of a pool, it also gets access to various electricity markets, which are not available to small customers. By participating in those markets, the heat pumps can save operational costs: the energy costs can be reduced by optimizing the consumption of the heat pumps towards cheap electricity prices on the day-ahead spot market. Furthermore, they can save costs or earn revenues by offering their flexibility to the balancing markets. When participating in the balancing markets, the heat pumps can additionally benefit from reduced grid costs.

However, when heat pumps participate in the electricity markets and their operation is therefore market-driven rather than heat-driven, some negative impacts have to be considered.

In the project iWPP-Flex [8], where heat pumps in single family homes were optimized for the day-ahead and balancing market, three main impacts were identified: When the heat pumps operate market-driven, the amount of their operational hours is higher than when they operate solely heat-driven. The number and frequency of the switching-cycles increases, which might have a negative impact on the life-time of the heat pump. Furthermore, the heating system temperature is often increased, which decreases the efficiency.

In a study by RWTH Aachen [9], a simple controller was used to optimize the heat pumps for the day-ahead spot market. In the study, the system temperature was also increased, resulting in high efficiency losses. In this case, the losses were so high that they made the additional revenues from the market nearly negligible.

Finally, the PHD-thesis from David Fischer of KTH [10] also confirmed the possible decrease in efficiency, as well as higher storage losses, due to higher system temperatures.

To summarize, the three analyzed studies found the following possible impacts of the market-driven operation of the heat pumps:

1. <u>Reduced life-time of the heat pump, due to a higher number of switching cycles:</u>
   This is prevented in the optimization, by modulating the power of the heat pumps. While operating in the balancing market, they are always switched on with at least 50% of their capacity and never switch on and off completely more than 4 times per hour.

2. Higher losses due to higher system temperatures:
   This is also considered in the operational optimization. The storage losses are dependent on the load of the storage. The higher the storage load, the higher its losses. In the optimal operational strategy, the storage is only filled to high loads, if the additional losses can be compensated by high enough market prices.

3. Reduced efficiency of the heat pump due to higher system temperatures:
   This effect is neglected in the optimization model. In order to keep computational times manageable, it is a goal to keep the optimization model in a linear form (with the exception of a few binary constraints). However, having the efficiency of the heat pump dependent on the storage temperature is a non-linear effect. This can therefore not be included in the simplified, linear model.

4. Reduced efficiency of the heat pump due to a higher number of switching cycles / frequent power changes:
   When heat pumps are turned on or change their power, their efficiency is lower than when they are running with a constant power. However, this effect could also not be directly implemented linearly and was therefore neglected in the analysis.

3 Development of business models (Task 4.1)

In this chapter the economic feasibility of the use cases is evaluated and two business models are proposed. The business model 1, considers the investment of all the components in an existing thermal network, while the business model 2 considers only the integration of a heat pump into an already existing thermal network. The calculations are included in the master thesis “Geschäftsmodelle für die Integration einer Wärmepumpe in Hochtemperatur Fernwärmenetze”, developed in the framework of the project fit4power2heat [11].

The feasibility assessment is done in an internal calculation tool used by *ENGIE Austria GmbH* to evaluate new investments. The tool is based on the annuity method, which is used to determine the depreciation on an asset by calculating its rate of return as if it was an investment. The methodology followed is presented in Figure 13. The inputs introduced in the tool consist of the simulation results (optimized operational costs, optimized operation strategy) and economic data (investment costs, maintenance costs, grid costs, fuel and electricity prices). The tool evaluates each use case under state-of-the-art and future conditions. As a result, the tool calculates the following key figures needed to configurate the business models: Internal Rate of Return (IRR), the Return Of Capital Employed (ROCE) considered on 3 years and the Earnings Before Interest and Taxes (EBIT - Margin). The economic key figures of the results are described in detail in chapter “3.2 Tool output: economic key figures2.

Figure 13: business model calculation process

3.1 Tool input: economic data

The input data for the economic calculation tool consist of investment costs, O&M costs, subsidies and grid costs.

Table 2 shows the investment costs considered for the biomass boiler, thermal storage, heat pump, flue gas condenser and the heat exchanger. These costs include subsidies and one-time grid costs.

Table 2: overview of the investment costs (subsidies and one-time grid costs are included)

Components	Baseline A	A	Baseline B	B-FG	B1-SW	B2-SW	Baseline C	C
Biomass boiler	350.000€ (2.400kW) 140.000€ (800 kW)	350.000€ (2.400kW) 140.000€ (800 kW)	84.000€ (500kW)	84.000€ (500kW)	84.000€ (500kW)	84.000€ (500kW)	84.000€ (500kW)	84.000€ (500kW)
Thermal storage	68.000€ (100m^3)	68.000€ (100m^3)	23.200€ (30m^3)	23.200€ (30m^3)	23.200€ (30m^3)	23.200€ (30m^3)	13.200€ (16,5m^3)	13.200€ (16,5m^3)
Heat pump	-	73.011€ (224 kW_{th})	-	33.317€ (102 kW_{th})	34.665€ (102 kW_{th})	69.331€ (204 kW_{th})	-	33.317€ (102 kW_{th})
Flue gas condenser	-	56.700€	-	25.704€	-	-	-	25.704€
Heat exchanger	-	-	-	-	39.375€	78.750€	-	-

(1) Source of the biomass boiler investment costs: data provided by ENGIE Austria GmbH
(2) Source of the thermal storage investment costs: data provided by ENGIE Austria GmbH
(2) Source of the heat pump investment costs: [12]
(3) Source of the flue gas condenser costs: [12]
(4) Source of the sewage water heat exchanger investment costs: 750 €/$kW_{extracted}$ [13]

The operation and maintenance (O&M) costs of the system components are considered as a percentage of the investment costs (Table 3). The estimated O&M costs are 2% of the investment costs for the biomass boiler and the heat pump, and 1% of the investment costs for the buffer tank, the flue gas condenser and the heat exchanger for the external heat source.

Table 3: annual O&M costs in percentage of investment costs

Components	**Annual O&M costs [% of investment cost]**
Biomass boiler	2
Thermal storage	1
Heat pump	2
Flue gas condenser	1
Heat exchanger	1

Kommunalkredit Public Consulting GmbH (KPC) [14] offers subsidies for several energy suppliers and components. The funding rates can vary depending on a set of technical, economic and regulatory requirements defined for each component. Table 4 shows the basic funding rates applicable to biomass boilers, thermal storages, heat pumps, flue gas condensers and heat exchangers.

Table 4: funding rates in percentage of investment costs

Components	Funding rate [% of investment]
Biomass boiler	30
Thermal storage	20
Heat pump	20
Flue gas condenser	30
Heat exchanger	30

The grid costs considered are described in the deliverable D2.1.

3.2 Tool output: economic key figures

In order to make a statement about the profitability of the individual use cases, the following economic key figures are calculated:

Internal rate of return (IRR):

The internal rate of return is the rate of return on the capital committed in an investment project or in a financing operation. The internal interest rate informs about the return on investment projects or the effective interest rate of financing measures. The internal rate of return is the discount rate at which the net present value of the investment project or financing measure is zero. The present value of the deposits corresponds in this case to the cash value of the payments [15].

The internal rate of return thus shows whether the investment will pay off in the long term when viewed over the entire term. The higher the rate of return, the more profitable the investment.

Return on Capital Employed (ROCE):

The key figure ROCE indicates how efficiently a company deals with the invested capital. The key figure is calculated by dividing the earnings before interest and taxes (EBIT) by the capital employed [16]. When analyzing business models, this value must be above 10% to make the investment meaningful. As long as this value is reached, the level of the key figure is not indicative of the cost-effectiveness of the use case. The ROCE metric is calculated as follows:

ROCE = (NOPAT (Net Operating Profit After Taxes)) / (Fixed Assets + Working Capital) [17]

Earnings before interest and taxes (EBIT):

The key figure EBIT determines the earnings before interest and taxes and provides information on the profitability of a company's operating business. This last can be compared to other companies by the EBIT, regardless of financing forms and regional taxation [18]. The EBIT is calculated as follows [17]:

Net income

+ Income taxes

= EBT (Earnings before Tax)

+ Borrowing interest

= EBIT (Earnings before Interest and Tax)

The EBIT-margin in percentage is used to compare the profitability of the use cases in the business models. The higher the EBIT-margin of a use case is, the more economical it is. This is calculated as follows:

EBIT-margin in % = (EBIT * 100) / revenues [17]

The feasibility assessment is based on the key figures IRR, ROCE and EBIT-margin. These are crucial for evaluating a business model in a company and making an investment decision. Since the

IRR and the ROCE provide information on whether an investment is feasible from the point of view of a company, these key figures must exceed the 10% threshold so that an investment can be made for the respective business model. No investment possibility is considered for business models with an IRR and a ROCE below 10%.

In a second step, the EBIT is examined, which indicates which of business models that have overcome the hurdle rate of the IRR and ROCE shows the best feasibility results.

3.3 Business model Canvas

The configuration of the business models is based on the business model canvas, which is a strategic management and lean startup template for developing new business models. It consists of a visual chart divided in the following nine categories that show the values of a business model: key partnerships, key activities, key resources, value propositions, customer relationships, channels, customer segments, revenue streams and cost structure. Figure 14 shows the configuration of the business model canvas according to the key values defined in the project *fit4power2heat*.

Key partnerships are created with high-quality suppliers in order to create efficient, streamlined operations and reduce the risks associated with any business model. Key partnerships are the network of suppliers and partners who complement each other in helping the company to create its value proposition. Partnerships can be categorized as strategic alliance between competitors, joint ventures and relationships between buyers and suppliers. In this case, the main key partnerships in the heating sector are the component manufacturers (heat pump, boiler and thermal storage manufacturers) and in the electric sector the balancing energy pooling provider, the power grid operator and the energy supplier.

Key activities are those activities which are essential to produce the company´s value proposition. These activities are the most important processes that need to occur for the business model to be effective. Key activities will coincide with revenue streams. The key activities associated with the business models developed in *fit4power2heat* are the evaluation and identification of suitable thermal networks, the integration of heat pumps in the network and the optimal operation of the thermal network in combination with the participation in the balancing markets.

Key resources are the assets of the organization associated to the value proposition to its customers. Resources can be categorized as human, financial, physical and intellectual. In the particular case of the business models developed, the key resources include market access, employees and know-how in energy trading, operation of thermal networks and heat pumps.

Value proposition is the combination of products and services offered by the company. These need to be unique and easily differentiated from the competition. Value propositions can be divided in quantitative (it stresses the price or efficiency of the product or service) and qualitative (it highlights the experience and results of the product or service). The integration of a heat pump in a thermal network leads to several benefits. It can increase the efficiency of the overall thermal network while lowering the heat generation costs. Additionally, the heat pump can support the electricity operators by participating in the balancing energy market and gain revenues from it. Besides, heat pumps offer the possibility to use alternative sources, such as flue gas or sewage water, and they offer a reliable heat supply.

Customer relationship must be selected in order to create financial success and sustainability. In this case, a reliable heat delivery to the customers must be ensured and the customers must be assisted by a quick troubleshooting process

Channel is defined as the medium through which an organization provides its value proposition to its customer segment. There are several options for channels available and the selection is based on the channel that is the quickest and most efficient, with the least amount of investment required. The following channels are considered: key account management, e-mail, phone and web site.

Customer segments are an essential part of a business model and are key to ensuring that the product features are aligned with the segments' characteristics and needs. The target customer segments considered are the heating plant operator and the thermal network operator.

A revenue stream is the methodology followed to get the customer segments to buy a certain product or service. The revenue stream can be created by lowering the heat generation costs, increasing the revenues provided by the participation in the balancing market and increasing the EBIT.

Cost structure defines the cost of running a business according to a particular model. The business models are cost driven since they focus on minimizing the overall operational costs. The following costs are identified: investment costs (biomass boiler, thermal storage, heat pump and sewage water heat exchanger), electricity costs, grid costs, fuel costs, operation and maintenance costs. The assessment of these costs and the evaluation of the feasibility of the use cases is presented in the following chapters.

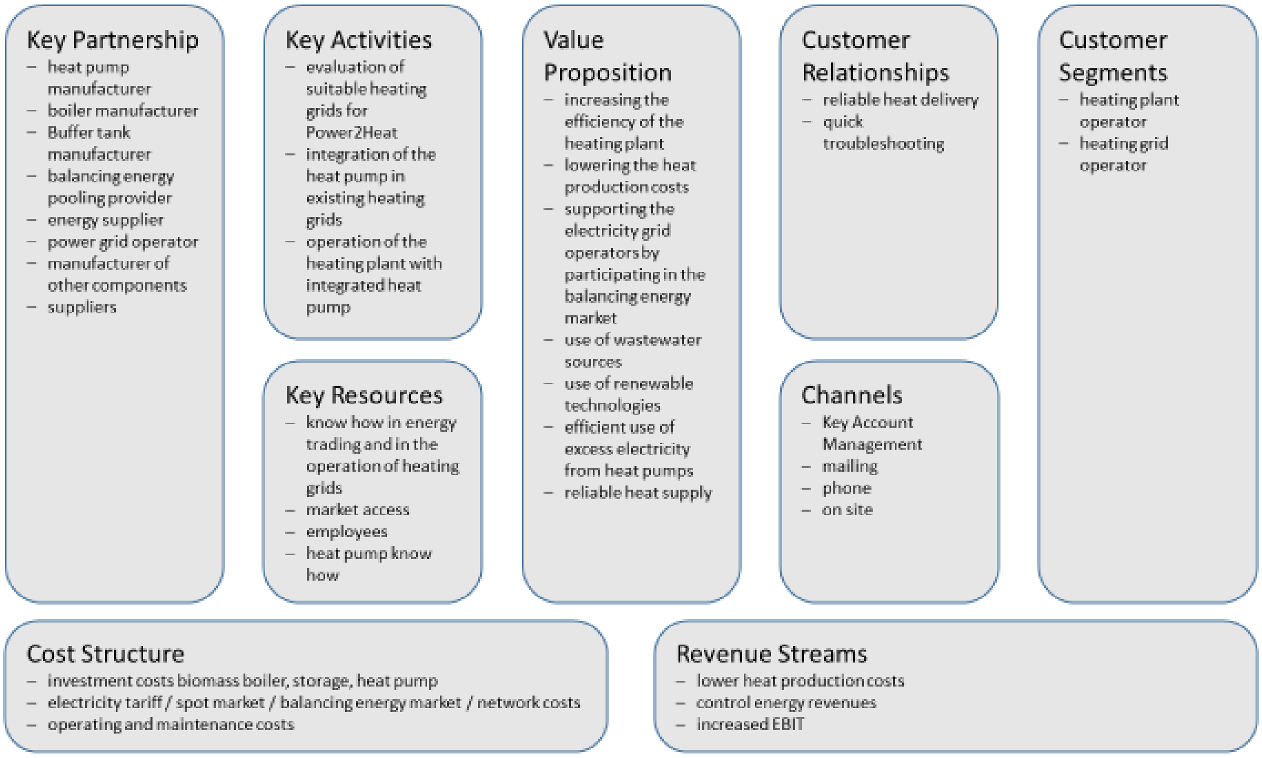

Figure 14: business model Canvas

3.4 Business model 1

Business model 1 is based on the following scenario: It is assumed that the biomass boilers installed in the thermal networks have almost reached the end of their lifetime and are operating unprofitably. Therefore, a reinvestment in new boilers is made. In the case of concept B, there are two equivalent boilers operating on an alternating basis. The second boiler is used as a back-up, therefore only one of the two boilers is renewed. The thermal storage is also replaced in each concept. In order to support the operation of the boilers and increase the overall efficiency of the system, a heat pump in installed, together with a flue gas condenser or a heat exchanger, depending on the heat pump source. The pipping and digging costs are excluded since the thermal network is not newly built and only the replacement of the components is considered.

3.4.1 Results

Figure 15 shows the investment costs for the system components in each concept. The subsidies are included (Table 4), as well as the one-time grid cost associated with the connection of the heat pump to the electricity grid (described in the deliverable D2.1).

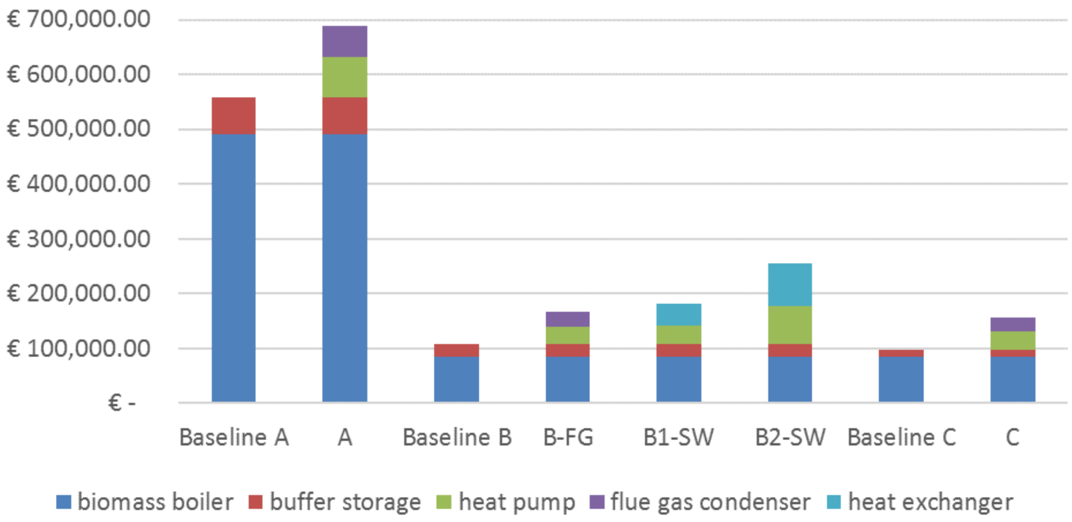

Figure 15: business model 1- comparison of investment costs

The results of the business model are presented by using the key figures IRR, ROCE and EBIT, defined in chapter "3.2 Tool output: economic key figures". While the IRR provides information on the profitability over the entire term, the ROCE ratio shows the capital employed over a period of three years. The marginal value for those key indicators is set to 25% of the baseline use case.

Figure 16 shows the IRR of the individual use cases. Relative values are presented due to confidentiality reasons. Therefore, a IRR value of 100% is assigned to the baseline use case. The IRR for those use cases with heat pumps is located below the IRR value for the baseline use cases. The highest IRR value amounts up to 85%, which corresponds to the use case A3. This use case combines the day ahead market with aFRR, considering low revenues and a high probability to be called. The lowest IRR values correspond to B3.2-SW (31%), which can be explained by the high investment costs associated to the large heat pump in combination with the sewage water heat exchanger. Nevertheless, the IRR value is above the threshold of 25% in all use cases, which means that an investment in any of the use cases would be feasible.

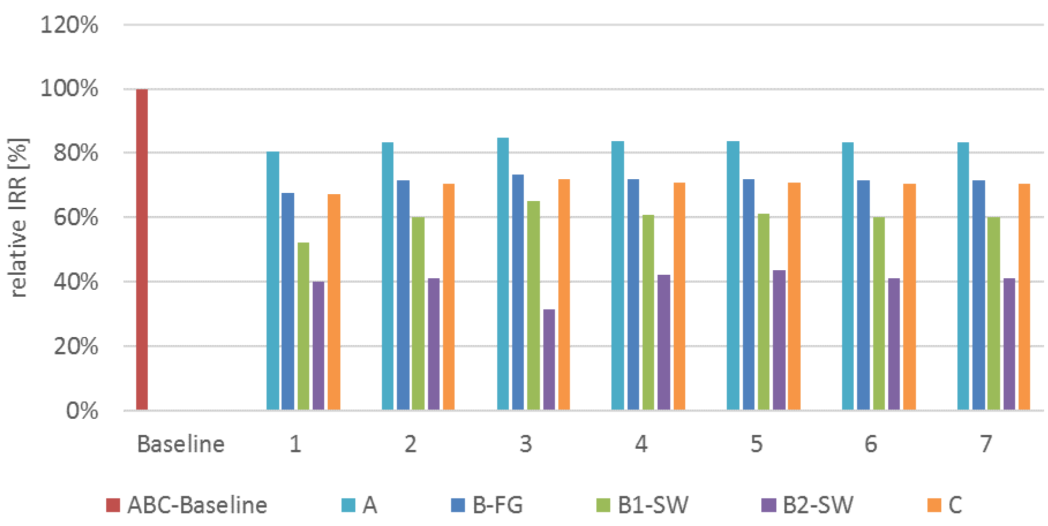

Figure 16: Internal Rate of Return (IRR) for business model 1

The long-term investment analysis over the entire term of 20 years shows that all use cases are economically feasible, since the ROCE is above 25%. As long as this hurdle rate is reached, the level of the key figure is not indicative of the cost-effectiveness of the use case. Figure 17 shows that the highest ROCE corresponds to the use case A3, while the ROCE for the use cases of concept B2-SW barely exceeds the hurdle rate, due to the high costs associated to the large heat pump in combination with a sewage water heat exchanger.

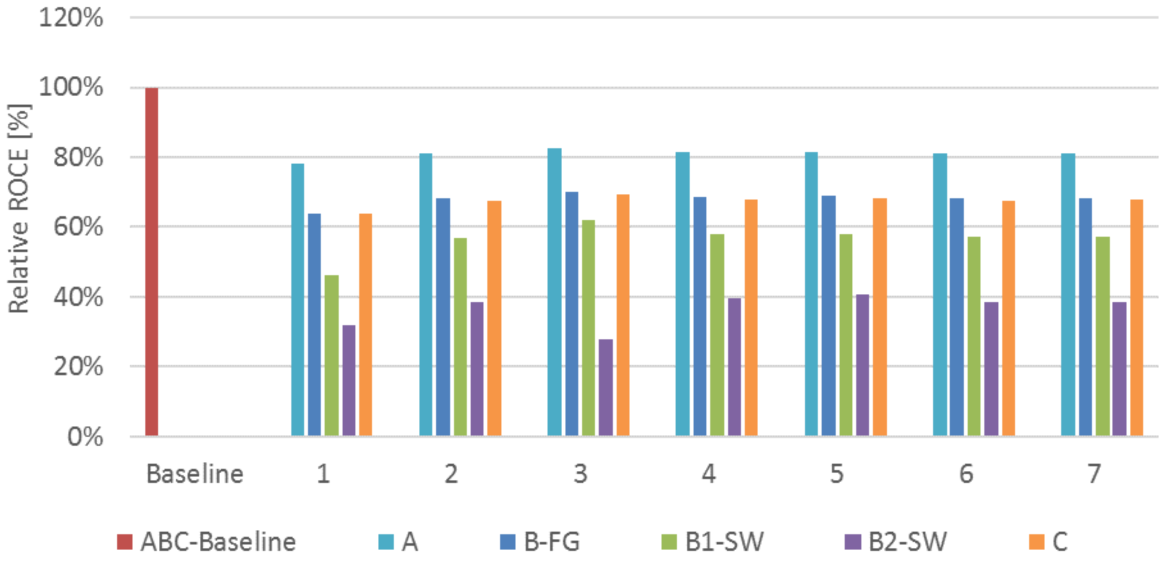

Figure 17: Return on Capital Employed (ROCE) for business model 1

From a business perspective, the key figure EBIT is the decisive factor when deciding on a business model. The higher the EBIT, the higher the profit of the company. The marginal value for the EBIT is set to 25%, therefore all use cases should reach it in order to be feasible. Figure 18 shows the EBIT-margin value for all use cases. It can be seen, that concept A and C improve the EBIT value of the baseline. Specifically, concept C, which uses the flue gas of the biomass boiler as the heat source for the heat pump, is the most attractive option with an EBIT value around 108% compared to the baseline. The strategy of electricity procurement on the day-ahead spot market, including participation in the secondary balancing market, with low energy prices and high call probability is the most interesting from an economic point of view. This strategy is shown in Figure 18 as “3” (X-axis). Among the use cases with this market combination, “A3”, “B3-FG” and “B3.1-SW are economically interesting as well with EBIT values between 97% and 105%. In overall, the use cases with flue gas as a source for the heat pump achieve better results in comparison to those use cases with sewage water, due to the lower investment costs.

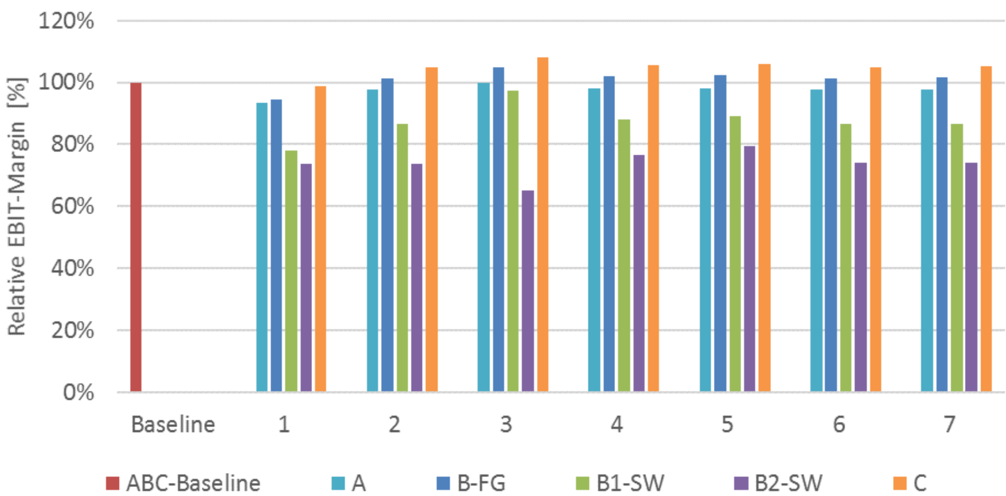

Figure 18: Earnings Before Interest and Taxes (EBIT) for business model 1

In overall, the economic results show that the concept C presents the most interesting economic results. In particular, the use case "C3" presents the most economically feasible technical solution. Compared with the baseline, however, the increase in EBIT is below 10%, which means that the risks associated must be evaluated in the investment decision. Therefore, a quantitative and qualitative sensitivity analysis is carried out. The last one is included in chapter "3.6 Qualitative analysis of the business models".

In order to counteract the high investment costs associated to upgrading the energy system, alternative financing models can be further analysed, such as contracting, external financing (crowdfunding, crowdlending), leasing and factoring, involving the customer and the supplier in order to minimize the risks. These business models would reduce the investment risk for heat suppliers, which has a positive effect on investment decisions, and manufacturers could benefit from increasing product sales and long-term business relationships (warranty, maintenance, insurance, etc.).

3.4.2 Sensitivity analysis

The quantitative analysis consists of a sensitivity analysis, which examines the influence of future market developments on the EBIT value. The use cases "B3-FG" and "B3.1-SW" are used as representative examples of the two heat pump integration possibilities (flue gas as a source and sewage water as a source respectively). These use cases are simulated in the framework of the future scenario described in deliverable D3.1, chapter 4.4 "Definition of state-of-the-art and future scenarios". The simulation output is assessed in order to analyze how future variations in electricity prices, biomass prices and call probabilities could affect their feasibility.

Table 5 presents the positive and negative variability of the variables mentioned. The investment costs and subsidies of the system components are not considered since a variation above 10% is not expected in the next few years.

Table 5: variability of parameters in the future scenario

Variables	Variability
Biomass price	± 10 %
Day-ahead prices	± 25 %
aFRR price	± 20 €
Call probability	- 25 % - 50 %

Figure 19 shows the EBIT-margin results of the quantitative sensitivity analysis for the use case "B3-FG", which considers flue gas as a source for the heat pump. The EBIT value is represented for the following scenario configurations (for further references on the parametrization of the state-of-the-art and future scenarios check deliverable D3.1, chapter "4.4 Definition of state-of-the-art and future scenarios"):

- Baseline biomass price (± 10%): it represents the EBIT value for the use case "B-baseline", which does not include a heat pump. The EBIT value is given for the current scenario (red dot) and future scenario (blue and green marker). The blue marker represents negative variability, while the green marker shows positive variability.

-Spot price (± 25%): it represents the EBIT value for the use case "B3-FG", which includes a heat pump with flue gas as a source. The EBIT value is given for the current scenario (orange marker) and future scenario (blue and green marker), where a variability of ± 25% over the state-of-the-art scenario is assumed for the day-ahead market price in the future scenario.

-Biomass price (± 10%): it represents the EBIT value for the use case "B3-FG", which includes a heat pump with flue gas as a source. The EBIT value is given for the current scenario (orange marker) and future scenario (blue and green marker), where a variability of ± 10% over the state-of-the-art scenario is assumed for the biomass price in the future scenario.

-aFRR price (± 20€): it represents the EBIT value for the use case “B3-FG”, which includes a heat pump with flue gas as a source. The EBIT value is given for the current scenario (orange marker) and future scenario (blue and green marker), where a variability of ± 20€ over the state-of-the-art scenario is assumed for the aFRR product price in the future scenario.

-Call probability (-25€/-50€): it represents the EBIT value for the use case “B3-FG”, which includes a heat pump with flue gas as a source. The EBIT value is given for the current scenario (orange marker) and future scenario (blue and green marker), where a decrease of 25€ and 50€ over the state-of-the-art scenario is assumed for the call probability in the future scenario.

The variable which has the highest influence on the EBIT-margin is the biomass price. A 10% variation improves or worsens the relative EBIT-margin value by around 7% for the use case “B3-FG”. An increase on the biomass price leads to a decrease on the EBIT value. This is explained by the fact that in this use case the flue gas is used as a source for the heat pump, which means that the heat pump and the biomass boiler operation are coupled. However, this decrease does not result in a lower EBIT value than the baseline use case, which means that the use case with a heat pump always presents higher EBIT values regardless the biomass price fluctuation.

The variables with the least influence on the EBIT are the day-ahead electricity price and the aFRR energy price. A variation of ± 25% on the day-ahead electricity price leads to a minimal EBIT-margin deviation of around 1%. The same result is achieved by adjusting the aRR energy price by ± 20 €. Regarding the call probability, reductions of 25% and 50% result in a EBIT-margin decrease of around 1,5% and 3% respectively. In overall, it can be seen that the EBIT value for the use case “B3-FG” always stays above the baseline regardless the development of the variables. This means that in principle the implementation of a heat pump is economically feasible and improves the profitability of the baseline. The small variability of the EBIT value under future fluctuations in biomass and electricity prices, as well as call probabilities, is an indicator of the robustness of the solution proposed.

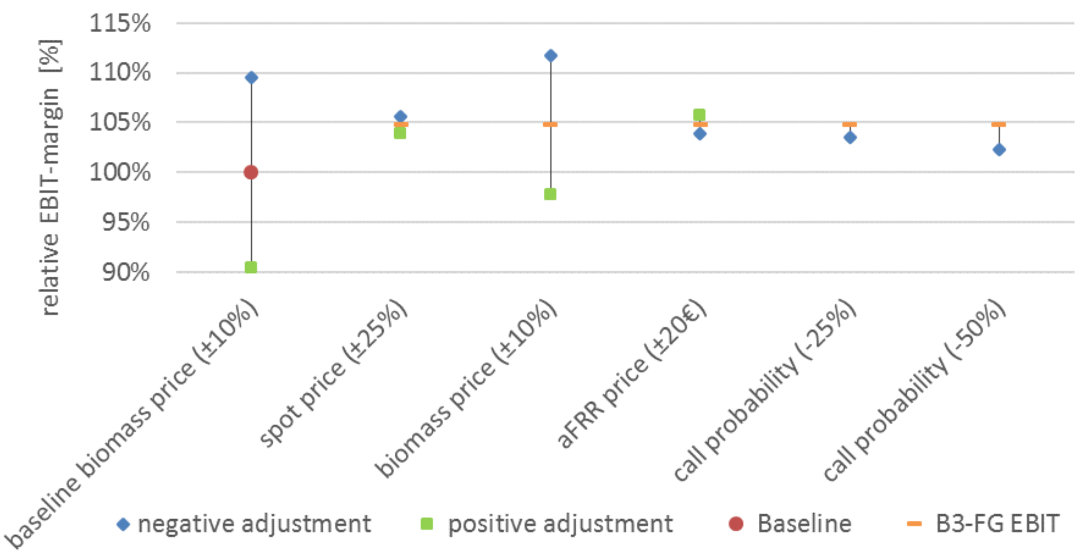

Figure 19: EBIT value for state-of-the-art and future scenarios. Business model 1, use case “B3-FG”.

The EBIT values calculated for the use case “B3.1-SW”, which considers sewage water as a source for the heat pump, are shown in Figure 20. The scenario configurations are analogue to those in Figure 19. Unlike the use case “B3-FG”, this use case is less sensitive to variations in biomass prices. This is explained by the fact that the biomass boiler and the heat pump operation are not coupled, since the heat pump uses sewage water instead of flue gas. The biomass price is still the variable with the highest influence on the EBIT value but it leads to smaller variations in comparison to the use case “B3-FG”. A variation of the biomass price by 10% price would result in a 6% variation of the EBIT. However, variations in the electricity prices and call probabilities have a greater influence in this case. The strongest reduction in the EBIT value (around 6%) occurs when the call probability decreases by 50%.

The comparison between the baseline use case (“baseline biomass price ± 10%” in X-axis) and the use case with a heat pump (“biomass price ± 10%” in X-axis) shows that if the biomass prices would decrease by 10%, a use case with no heat pump would be economically more attractive. On the contrary, if the biomass prices would increase by 10%, implementing a heat pump would be a more interesting option, since it would present higher EBIT values.

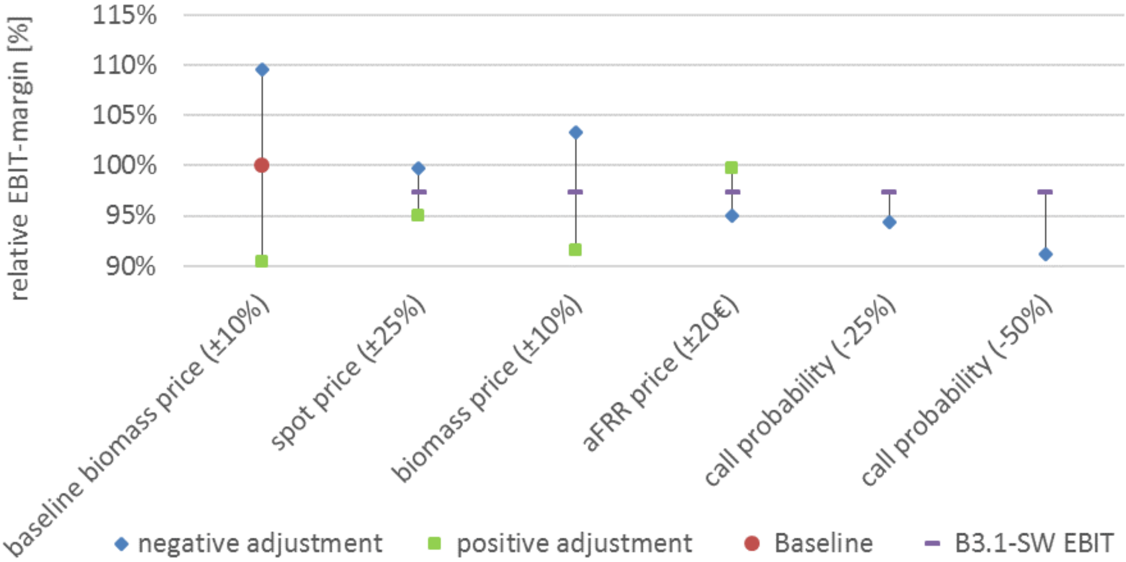

Figure 20: EBIT value for state-of-the-art and future scenarios. Business model 1, use case “B3.1-SW”.

3.5 Business model 2

Business model 2 is applicable to those thermal networks, where only an investment in a heat hump is being considered. It is assumed that the thermal network, already equipped with a biomass boiler and a thermal storage is operating profitably. In this context, the heat pump installation offers the possibility to increase the overall efficiency of the system, reduce the fuel expenditure and increase the revenues. This chapter includes an economic assessment of the different use cases.

3.5.1 Results

Figure 21 show the investment costs considered for each concept. They include the subsidies for each component (shown in Table 4), as well as the one-time grid costs associated with the connection of the heat pump to the electricity grid (described in the deliverable D2.1). The biomass boilers and the thermal storage are not replaced, therefore their investment costs are excluded. The investment costs for business model 2 are lower compared to business model 1 and there are no investment costs associated to the baseline, since the aim of the assessment is to compare the benefits that a heat pump integration brings to an already built network.

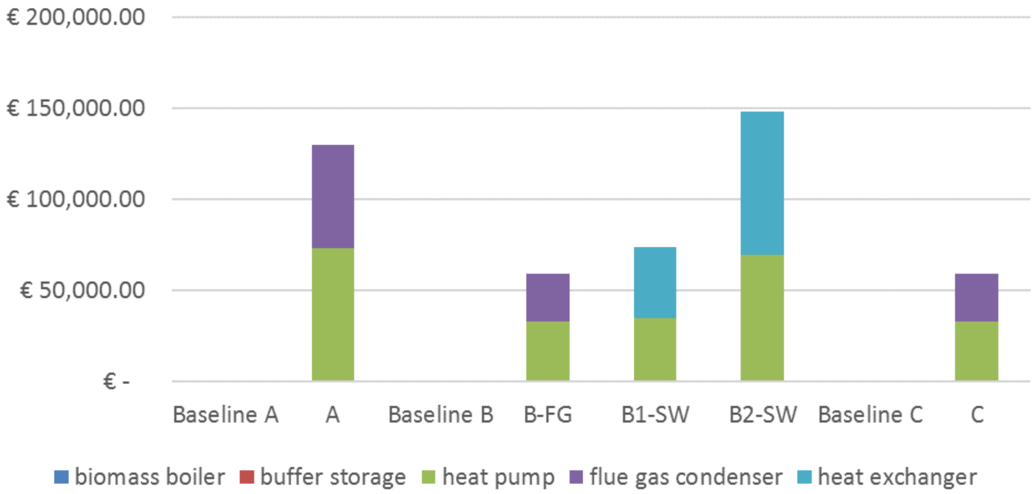

Figure 21: business model 2 - comparison of investment costs (subsidies and one-time grid costs included)

Due to the fact that no investment is made in the baseline use cases, no comparison of the IRR and the ROCE is done. The results of the EBIT are shown in Figure 22. The EBIT values have similarities to those calculated in business model 1. Business model 2 presents benefits for the use cases with the highest investment costs, corresponding to B1-SW and B2-SW, which consider sewage water as a source for the heat pump. The EBIT increase can reach up to 10% in business model 2 compared to business model 1. This is the case for the variation "B2-SW" in the market combination 3 (day-ahead and aFRR, with low electricity prices and high call probabilities). However, the EBIT value for the use cases with sewage water as a source is lower than the baseline value. A condition to increase the EBIT above the baseline value is to keep the investment cost of the sewage water heat exchanger below 750 €/kW$_{extracted}$ for the concept B1-SW and below 550 €/kW$_{extracted}$ for the concept B2-SW.

Once again, the use case "C3" presents the best results since the EBIT is 8% higher than the baseline value. It presents the same EBIT value in business model 1 and 2, since the investment costs for the biomass boiler and the thermal storage are the lowest among the use cases analyzed. Therefore, excluding them from the investment strategy, as it is proposed in business model 2, does not influence the final result.

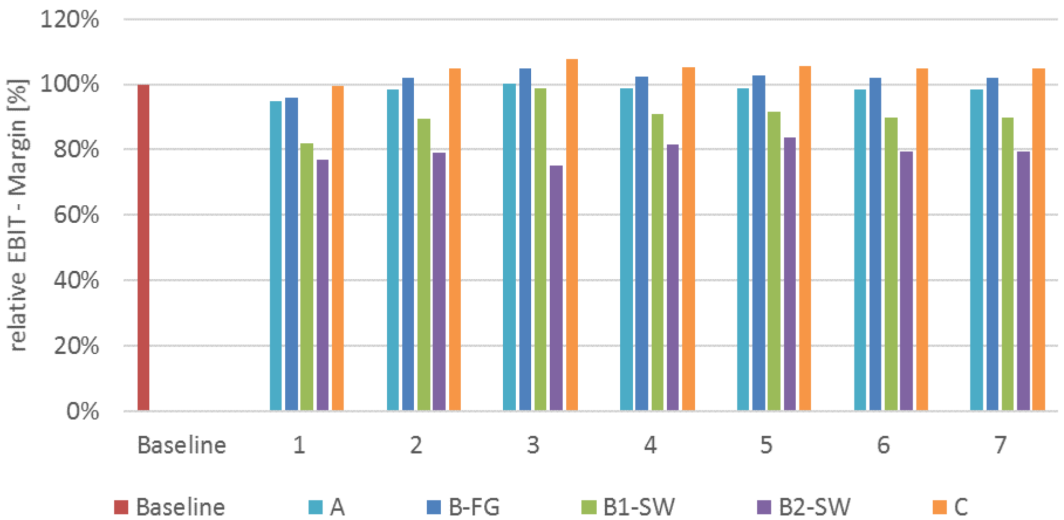

Figure 22: Earnings Before Interest and Taxes (EBIT) for business model 2

In overall, concept C is presented as the most feasible option in business model 2. In particular, the use case "C3", which considers the day-ahead market in combination with aFRR is the most interesting use case. Concept B-FG could be an attractive option since it improves the EBIT values in some cases. However, the EBIT increase compared to the baseline is below 10%, therefore the risks associated must be evaluated in the investment decision.

3.5.2 Sensitivity analysis

A quantitative sensitivity analysis is carried out on the basis of the method presented in chapter "3.4 Business model 1", in which the influence of future market developments on the results is assessed. The use cases "B3-FG" and "B3.1-SW" are used as representative examples of the two heat pump integration possibilities (flue gas as a source and sewage water as a source respectively). They are simulated under future conditions and the simulation output is assessed in order to analyze how future variations in electricity prices, biomass prices and call probabilities could affect their feasibility.

Figure 23 presents a comparison of the EBIT results for the state-of-the-art and future scenarios in the use case B3-FG. Like in business model 1, the variable which has the highest influence is the biomass price. This can be explained by the fact that the biomass boiler and heat pump operation are coupled, since the flue gas is used as a source for the heat pump. Therefore, a 10% decrease in the biomass prices would result in a 6% increase of the EBIT. On the contrary, the use cases with flue gas a source are barely sensitive to variations in electricity prices and call probabilities, since the EBIT margin always stays below 1%.

The comparison between the baseline use case ("baseline biomass price ± 10%" in X-axis) and the use case with a heat pump ("biomass price ± 10%" in X-axis) shows that regardless the variation in the biomass prices, implementing a heat pump would be economically a more attractive option, since it always presents higher EBIT values.

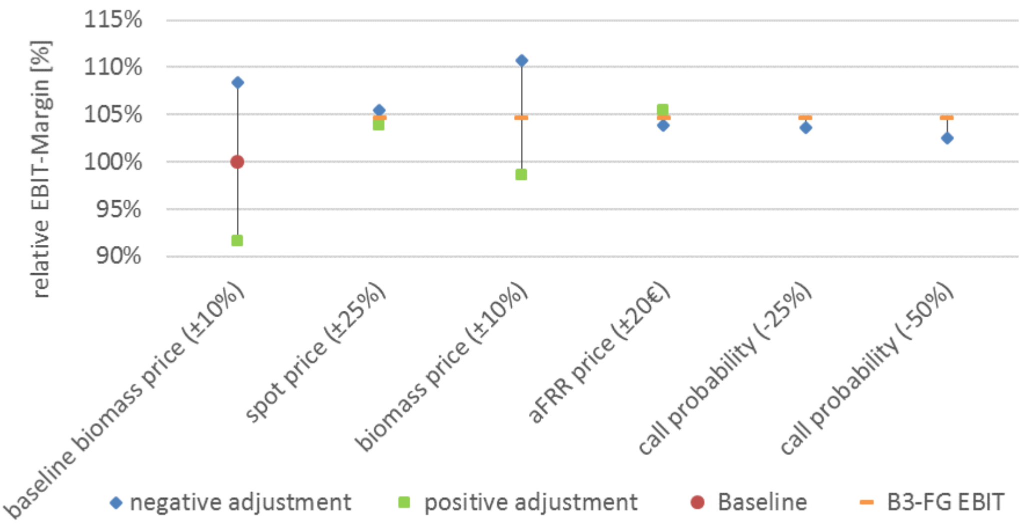

Figure 23: EBIT value for state-of-the-art and future scenarios. Business model 2, use case "B3-FG"

Figure 24 shows the EBIT results for the state-of-the-art and future scenarios of the use case "B3.1-SW". The biomass price is the variable with the highest influence in the EBIT value. However, it leads to smaller variations in comparison to the use case "B3-FG" (around 5%). The comparison between the baseline use case ("baseline biomass price ± 10%" in X-axis) and the use case with a heat pump ("biomass price ± 10%" in X-axis) shows that if the biomass prices would decrease by 10%, a use case with no heat pump would be economically more attractive. On the contrary, if the biomass prices would increase by 10%, implementing a heat pump would be a more interesting option, since it would present higher EBIT values. The use cases with sewage water are more sensitive to variations in the electricity prices and call probabilities, since the operation of the biomass boiler and heat pump is not coupled. The strongest variation in the EBIT value (around 6% reduction) occurs when the call probability decreases by 50%.

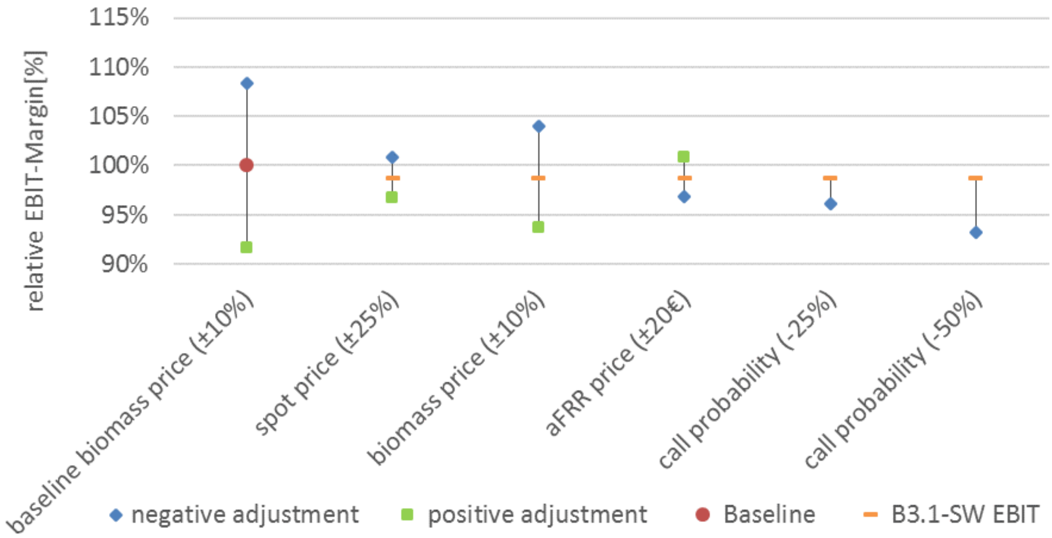

Figure 24: EBIT value for state-of-the-art and future scenarios. Business model 2, use case “B3.1-SW”

3.6 Qualitative analysis of the business models

In addition to the quantitative sensitivity analysis (included in chapters “3.4 Business model 1” and “3.5 Business model 2”), the business models are evaluated qualitatively in order to estimate the risk associated with the investment. Table 6 and Table 7 present the expected future developments in the electricity and heating sector, as well as their influence in the technical concepts and business models proposed. The future developments refer to variations in the market typology, demand (electricity and heat) and prices (fuel and electricity). The evaluation shows that positive developments for biomass and power-to-heat systems are expected, especially in the heating sector.

Table 6: future developments in the electricity sector. Impact on the business models.

Future development	Impact level (*)	Description of the impact
Increase in the electricity demand	~	On the one hand, an increase in electricity demand can lead to higher electricity prices. On the other hand, new opportunities could arise for flexible consumers such as power-to-heat systems in the electricity market.
Reduction of product lengths in the balancing market	-	Lowering the product length to less than 4 hours would increase the number of technologies participating in the balancing market. Increasing the number of suppliers would negatively affect the revenues expected.
Transnational offers on the balancing energy market	-	An increase in the number of producers or consumers that can participate in an auction would lead to a higher competition and therefore, lower revenues.
Decrease of the reaction time in the market	~	When the reaction time required by the balancing market is shorter, this makes market participation more difficult. This results in less competition on the market, increasing possible revenues, but making the participation of heat pumps more difficult.
Mixed price method	~	The introduction of a mixed price (mixture of power and energy prices in the balancing market) would not have a major impact on the business models. Prices and revenues would change only minimally.

(*) Impact level on the business model: -- (strong negative), - (negative), ~ (neutral), + (positive), ++ (strong positive)

Table 7: future developments in the heating sector. Impact on the business models.

Future development	Impact level (*)	Description of the impact
Increase in oil and gas prices	+	An increase in oil and gas prices would have a positive impact on the biomass-based technologies. Since the biomass prices do not depend on the development of oil and gas prices, such a scenario might be likely.
Increase in heat sales price	++	Higher heat sale prices would lead to an increase of the overall revenues, making the business models more interesting.
Reduction of investment costs	++	A reduction in the investment costs of the system components (biomass boilers, thermal storages, heat pumps and sewage water exchangers) would improve the feasibility of the business models.
Increase in subsidies	++	Since the investment costs highly influence the business models, an increase in the funding rates assigned to power-to-heat systems would lead to more attractive business models.
Decrease in heat demand	-	A decrease in the heat demand, due to refurbishment measures in buildings among others, would influence the heat sales negatively.

(*) Impact level on the business model: -- (strong negative), - (negative), ~ (neutral), + (positive), ++ (strong positive)

4 Transferability of the technical solution and business models

This chapter evaluates the transferability of the technical solutions and business models proposed. The solutions are not only valid for the concrete thermal networks analyzed in the project *fit4power2heat*, but they are also applicable to other thermal networks in Austria.

The development of the concepts and use cases presented in deliverable D3.1 is done based on a literature review on typical thermal networks in Austria (deliverable D2.1), which ensures that they are representative. In order to validate the transferability of the technical solutions and business models proposed, a comparison between the use cases and the existing thermal networks in Austria is carried out.

The Table 8 shows the typology of existing biomass-based thermal networks in Austria. The data is extracted from the QM Heizwerke database [19], which is one of the most complete database regarding biomass-based thermal networks in Austria. The existing networks are sorted according to their annual heat demand: above 6,5 GWh (network type I), between 1,5 GWh and 2,2 GWh (network type II), between 2,2 GWh and 6,5 GWh (network type III). For comparison purposes, these threshold values correspond to the heat demand values of the concepts A, B and C presented in the deliverable D3.1. The networks are characterized in terms of heat demand, supply/return temperatures, type of heat plants installed, flue gas availability, condensation capacity, thermal storage capacity and availability of other renewable heat suppliers. The networks included in network type I are similar to concept A, the networks included in type II are similar to concept B and the networks in type III are similar to concept C.

According to Table 8, the number of existing thermal networks with similar characteristics to the networks analyzed in fit4power2heat are 261 for concept A, 85 for concept B and 250 for concept C. For example, the thermal networks with an annual heat demand above 6,5 GWh can be compared to concept A. The average supply temperature of concept A (78°C) is located in the range provided in the table (maximum: 128°C, minimum: 55°C). The average return temperature of concept A (46°C) is also located in the range provided (maximum: 75°C and minimum: 35°C). Besides, the mean storage volume is 95 m^3, which is almost equivalent to the storage volume considered in concept A (100 m^3). The thermal networks in this range have in total 85 flue gas condensers with an average condensation capacity of 798 kW. The large number of existing thermal networks with similar characteristics to concepts A, B and C presents a high potential for the transferability of the technical solutions developed.

Table 8: characterization of typical thermal networks in Austria **[19]**.

Parameter		Network I: >6,5GWh	Network II: >1,5 and <2,2GWh	Network III: >2,2 and <6,5GWh
Number of networks		261	85	250
Heat demand (heat losses included)				
Number of networks		261	85	250
Min	MWh	6,512	1,514	2,205
Max	MWh	448,157	2,198	6,462
Mean	MWh	24,639	1,840	3,892
Supply temperature				
Number of networks		261	85	250
Min	°C	55	73	70
Max	°C	128	95	120
Mean	°C	95	87	90
Supply temperature				
Number of networks		261	85	250
Min	°C	35	25	40
Max	°C	75	80	94
Mean	°C	56	56	56
Flue gas condensation				
Number of networks with condensation		85	0	33
Condensation capacity				
Number of networks		84		33
Min	kW	50		50
Max	kW	13,950		400
Mean	kW	798		182
Storage				
Number of networks with storage		161	69	191
Storage volume				
Number of networks with available data		147	65	175
Min	m³	10	5	0
Max	m³	900	60	150
Mean	m³	95	21	37
Number of networks with storage >100m³		36	0	7
Solar plants				
Number of networks with solar plants		12	4	11
Collector area				
Number of networks with available data		12	4	11
Min	m²	150	100	225
Max	m²	1,245	250	604
Mean	m²	552	185	378
Biomass-KWK / Biomass boiler				
Number of networks only with biomasse-KWK		11	0	1
Number of networks with biomass-KWK and biomass boiler		21	4	3
Number of networks only with one or more biomass boiler(s)		176	78	228
Number of networks with only one boiler		69	37	95

Additionally, multiple networks from ENGIE Austria GmbH´s business portfolio are evaluated in order to analyze if the technical solutions and business models developed within the project fit4power2heat can be applied to them. The potential for heat pump integration is assessed individually, based on the specific hydraulic and economic characteristics of each thermal network. According to the results, the integration of a heat pump is an interesting solution for many of the networks. As an example, some of them are presented below. They could be partially or totally refurbished by means of a heat pump, taking advantage of the technical and economic benefits of a heat pump pool, such as the improvement of the overall efficiency in the system and the reduction in the heat generation costs.

Network 1

- Boiler: 2 x 1MW Biomass (wood chips) (2010)
- Storage: 50 m³
- Flue gas filter: E-Filter
- Energy supply: 4,9 GWh
- Connection: 115 houses, 1 commercial building, 1 industry
- Supply/Return temperatures: 82/55°C. The return temperature does not drop below 50°C
- Flue gas temperature after the boiler: 140 – 180 °C

Due to the high flue gas temperatures and the already installed electrostatic precipitators, the installation of a flue gas cooler with condensation is a good option for this plant. The flue gas is cooled down to the dew point depending on the connection with combustion air preheating and/or de-steaming. A heat pump integration in this network would be interesting.

Network 2

- Boiler: wood chips. Capacity: 450 kW (2015), 300 kW (2006), 150 kW (2006)
- Storage: 20 m³
- Flue gas filter: E-Filter
- Energy supply: 600 MWh
- Connection: 150 customers
  Supply/Return temperatures: 75/50°C.
- Flue gas temperature after the boiler: 140 – 180 °C

This network requires an evaluation of the biomass boilers´ operation to analyze the heat supplied by each of them, as well as the decrease in the return temperature at these times. It should also be evaluated the need of installing 3 separate flue gas condensers.

Network 3

- Boiler: biomass 550 kW (2017), 150 kW (2009). Gas 400 kW.
- Storage: 55+6+4 m³
- Flue gas filter: E-Filter
- Energy supply: 1,1 GWh
- Connection: 86 customers
  Supply/Return temperatures: 85/53°C.
- Flue gas temperature after the boiler: no data available

This system is a district heating network with a gas boiler as a back-up. An optimization of the network would be required to reduce the return temperature. The option of flue gas condensation or cooling, together with a heat pump is interesting.

Network 4

- Boiler: gas 2x 550 kW (2013,2015), 1200 kW (2006).
- Storage: 50 m³
- Flue gas filter: E-Filter
- Energy supply: 2,5 GWh
- Connection: 1 industry
  Supply/Return temperatures: 65/50°C.
- Flue gas temperature after the boiler: 150 – 180 °C

The given supply and return temperatures show a high potential for the integration of a heat pump together with flue gas condensation.

Network 5

- Boiler: wood chips 500 kW (2009) + gas 400 kW
- Storage: 15 m³
- Flue gas filter: cyclone
- Energy supply: 1400+300 MWh
- Connection: 1 hotel
  Supply/Return temperatures: 80/55°C.
- Flue gas temperature after the boiler: 140 – 160 °C

The network presents high potential for a heat pump integration together with flue gas condensation

Network 6

- Boiler: wood chips 500 kW (2015) + gas 500 kW
- Storage: 10 m³
- Flue gas filter: cyclone
- Energy supply: 1750 MWh, 600 MWh
- Connection: 1 large customer
  Supply/Return temperatures: 70/50°C.
- Flue gas temperature after the boiler: 160 – 170 °C

High full-load operation hours of the biomass boilers result in a high potential for heat pump integration together with flu gas condensation.

Network 7

- Boiler: wood chips 550 kW (2018) + gas 400 kW
- Storage: 26 m³
- Flue gas filter: E-filter
- Energy supply: 1100 MWh, 300 MWh
- Connection: 80 customers
  Supply/Return temperatures: 70/50°C.
- Flue gas temperature after the boiler: no data available

The high full-load operation hours of the biomass boilers result in a high potential for heat pump integration together with flu gas condensation.

Network 8

- Boiler: wood chips 550 kW (2018) + oil 90 kW (back-up)
- Storage: 10+6+4+3 m³
- Flue gas filter: E-filter
- Energy supply: 950 MWh, 100 MWh

- Connection: around 900 kW (residential and non-residential buildings)
  Supply/Return temperatures: 70/50°C.
- Flue gas temperature after the boiler: 160 – 180 °C

The capacity of the biomass boiler is limited for the heat demand requirements in winter. Therefore, the operation of the boiler could be supported by the implementation of a heat pump together with a flue gas condenser. The installation of a larger thermal storage should also be considered.

Regarding follow-up activities, a demonstration project may be planned in the future. The use cases which showed better results in the feasibility study carried out in the project fit4power2heat present a higher potential for demonstration. Based on the technical solutions proposed, a more detailed analysis should be carried out on the hydraulics of the thermal networks selected and on the control system of the heat pumps. Future regulatory changes in the electricity market should also be considered, in order to evaluate their influence on the business models developed.

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