12th IEA Heat Pump Conference 2017

Business Models Using the Flexibility of Heat Pumps – A Discourse

David Fischer[a,b]*, Thomas Erge[a], Marc-André Triebel[a,c], Raphael Hollinger[a]

[a]Fraunhofer Institute for Solar Energy Systems, Heidenhofstr. 2, 79100 Freiburg, Germany
[b]*Royal Institute of Technology KTH, Brinellvägen 8, 11428 Stockholm, Sweden*
[c]*Aalborg University, Fredrik Bajers Vej 5, 9220 Aalborg, Denmark*

Abstract

In this work different business models that could arise from using the flexibility of residential heat pumps in a smart grid context are analysed. The investigated applications are: operation to reduce loading of the electric distribution grid, operation at the reserve markets, operation at the EEX spot market, operation to reduce the need for balancing-energy, operation to maximise PV self-consumption and operation to increase HP efficiency.
For each business case a three-level analysis is conducted. 1) The requirements, regulations, competences and strategic partners for each business model are analysed using the business model canvas method. 2) The possible revenue streams are estimated for a German single family house. 3) Finally a technical evaluation of the different options is conducted.
Results show that due to high-end costumer prices, grid fees and complicated market requirements, less integrated business models are more attractive than the direct use of heat pump flexibility in the reserve or spot market or providing balancing energy. However additional revenues could be generated by using heat pump flexibility. E.g. providing secondary reserve or balancing energy can yield additional revenues up to approx. 80 €/$kW_{HP,el}$/a for heat pumps.

Selection and/or peer-review under responsibility of the organizers of the 12th IEA Heat Pump Conference 2017.
Keywords: Heat Pumps, Flexibility, Electricity Markets, Demand Side Management, Business Model Canvas

1. Using the flexibility of heat pumps for business

Increasing efficiency of heat pump units and rising shares of electricity provided by renewable energy sources make heat pumps an increasingly attractive and ecologically favourable heating solution. By combination with a thermal storage or the activation of the building’s thermal mass, electric heat pumps offer the possibility to decouple heat generation from heat demand. This leads to flexibility in heat pump operation. When heat pumps are equipped with a communication device their flexibility can be used by a third party (e.g. the utility). This third party typically a company having a contractual agreement with the heat pump owner (or operator) to use the flexibility of individual heat pumps to generate additional profit, is considered the flexibility contractor in this study.

By using this flexibility, heat pump technology can help solving the challenges of the “Energiewende” in the power and heating sector, e.g. by providing services to the power grid or increasing the use of renewable electricity. However, flexibility will only be used if economically attractive and technologically feasible business cases can be identified. This study investigates important aspects of selected business cases for flexibility contractors. The focus is on the German market. The aim of this study is to support utilities, heat pump manufacturers and researchers with an economic analysis in order to screen and evaluate possibilities to profit from heat pump flexibility, and thereby enabling a successful integration of heat pumps into the future energy system.

1.1. Status quo: Emerging activities using distributed energy resources' flexibility

Today it is widely accepted that heat pumps connected to active or passive thermal storage options can be used for load shifting [1]. Research on enabling heat pumps to participate in a smart grid is mainly focussing on technological questions such as controls, grid integration and the potential for load shifting. A more market centred approach of enabling the use of decentralised energy resources is found in [2], where it is highlighted that for different type of services the market design, corresponding reaction timescales, and needed controls are different. Direct controls or time variable prices are seen as a key to influence the operation of distributed resources. [2] highlights that choice of controls has to be seen with respect to the market requirements and regulations.

The importance of customer-aggregator relationship in the form of contractual design is discussed in [3]. The authors differ between two general types of contracts for flexibility: Flat rate contracts where price is independent of usage and flex rate contracts where only the use is reimbursed. The two contracts mainly differ in allocation of risks as well as complexity and cost of management.

In recent years, companies mainly rooted in the PV sector, as well as traditional utilities have started to look at using flexibility of distributed resources such as PV-Battery systems or heat pumps. Lately heat pump manufacturers have entered the market for power supply and flexibility aiming to increase their service proposition and value of their products.

On a local level, energy management systems are used in order to increase PV self-consumption by adjusting heat pump operation or to operate particularly in hours of low electricity prices. To use the flexibility of heat pumps by an external body the most conventional approach is to allow blocking of heat pumps by the distribution system operator (DSO) up to 3x2 hours a day. This leads to reduced grid fees for heat pump unit and which is common practice in Germany. More recent concepts focus on using decentralised storage capacity (mostly batteries) and the possibility to curtail load in order to operate on the reserve markets or improving electricity buying conditions.

1.2. Motivation and explanation of investigated business cases

This study focuses on the role of a flexibility contractor, who uses and capitalises the flexibility of heat pump pools or individual heat pumps. Table 1 shows the most important players, their activities and potential business opportunities from the perspective of the flexibility contractor. The resulting business models that are further investigated in this paper are:

Offering services to the electric grid:

- Provision of reserve power: Revenues are generated through the provision of capacity and energy at the reserve markets.
- Reduction of grid fees: If the heat pump offers the possibility to be shut down by the grid operator it is considered as an interruptible load leading to reduced grid fees.
- Reduction of concession fees: If it is possible to operate heat pumps in a high-tariff/low-tariff scheme a reduction of concession payments can be achieved.

Offering services to the balance group:

- Optimised electricity purchase: Operation of the heat pump based on the forecasted electricity price at the spot market. Thereby reducing electricity buying costs.
- Reducing the need for balancing energy: Possibility to reduce/counteract forecasting errors within a balancing group leading to a reduced need for balancing energy.

Offering services to heat and electricity customers:

- Increasing self-consumption of onsite generated PV electricity with improved controls.
- Increasing efficiency: Reduced electricity consumption of the heat pump system due to improved controls using forecasts and operational data.

Table 1. Main players in the electricity sector, their task and potential business opportunities from a flexibility contractors perspective.

Player	Main task	Operative tasks	Goal	Business opportunity for HP flexibility
Transmission System Operator (TSO)	Electricity distribution	Voltage management Frequency management Organisation of reserve Reactive power management Redispatch	Stable transportation grid operation at low costs	Provision of reserve capacity/energy Grid reserve

Distribution System Operator (DSO)	Electricity distribution	Voltage management Grid access	Stable distribution grid operation at low costs	Peak load reduction (pos. & neg.)
Balance responsible party / Trading	Physical and contractual organisation of demand and supply	Balance group management Forecasting load/generation for TSO Purchase and sales of electricity	Accurate forecasts, thus reduced need for balancing energy Good trading deals (low costs purchase or high costs sales)	Reaction to forecast errors by adjusting load Optimised operation schedule
HP operators	Heat supply of living units	Heating of living units	Low heating costs	Efficiency increase PV self-consumption increase

2. Methodology

The potential business cases are analysed using qualitative and quantitative measures.

2.1. Qualitative analyses: Business Model Canvas and complexity assessment

The qualitative analyses of business models is based on the Business Model Canvas Method [4]. In the centre of each business case are the **customers**, who are proposed a **value**, and are reached through different **channels.** The generated **revenues** build the financial foundation of each business case. In order to enable a successful business, r**esources** and p**artners** are required, and **key activities** are constantly performed. This results in different fixed and variable **costs** for each business case.

2.2. Quantitative analyses: Revenue potential

Potential revenues defined as additional cash flows for a third party generated by using the flexibility are estimated in the following. They represent the foundation of each business case. A single family house, equipped with a 5 kW_P PV plant, situated in Germany is used for this case study. Table 2 provides key numbers. For each case a range of values is provided to account for the insecurities in the assumptions. The maximum possible revenue depends on market conditions but also on technical considerations. Heat pump electric energy and power can be used for different business cases. The theoretical upper bound to the available electric energy is the annual consumption of the heat pump unit. The nominal electrical capacity is used as the upper bound for power. The annual operation hours are set as the upper bound for the time a heat pump can be used to provide flexibility. All upper bounds will be reduced in practice. For this reduction literature values for flexibility for the different cases are used and build the foundation for estimating the possible revenues. In the following the calculation steps are briefly explained and summarised in Table 3.

Table 2. Assumptions used for estimating revenues from HP flexibility. All values are for 2015.

Assumption	**Value**	**Unit**
HP electricity tariff (work only)	19	ct/kWh
Feed-in tariff for PV (EEG 1.1.2015, roof mounted private)	12.3	ct/kWh
Grid fees	6.35	ct/kWh
Average price day-ahead EPEX	3.1	ct/kWh
Average daily q25/q75 price difference EPEX day-ahead	1.3	ct/kWh
Average daily q25/q75 price difference balancing energy	6.4	ct/kWh
Technical assumptions:		
Building type	Single Family House	
EL. Energy production of a 5kW_p PV	5000	kWh/a
El. Nominal power of HP	2.5	kW
Nominal operational hours	2500	h/a
Electricity consumed by HP	6250	kWh/a
Electricity costs for HP	1250	EUR/a

2.2.1. Provision of primary reserve

When participating in the primary control power market, it is assumed that the revenues are entirely generated from the supply of capacity. Revenues are estimated using the annual average capacity price p_{CP} and the hours $h_{participate}$ that a heat pump unit is participating in the market. Leading to:

$$Revenue = p_{CP} \cdot h_{participate}$$

Assumptions: Low value $h_{participate}$: Participating 50% of the annual HP operation time

High value $h_{participate}$: Participating 100% of the annual HP operation time
Average capacity price: 1.24 ct/kW/h

2.2.2. Provision of secondary and tertiary reserve

The provision of secondary and tertiary reserve leads to revenues that arise from the mere provision of capacity and the actual performance of work. Positive (HP is switched off) and negative (HP is switched on) reserve capacity are investigated separately. Providing negative reserve power leads to energy purchases at a different price, compared to the spot market price $\overline{p_{EPEX}}$. Providing positive reserve power leads to additional cash flow from p_{EP} but results in costs for the already purchased electricity. It is assumed that on average electricity can be bought for the average day-ahead spot price.

The individual bids on capacity prices (p_{CP}) and obtained tenders determine the hours $h_{participate}$ that a heat pump unit is participating in the market. The individual bids on reserve energy prices (p_{EP}) and obtained calls determine the energy $W_{el,calls}$. The corresponding revenues are calculated as:
Positive reserve power:

$$Revenue = p_{CP} \cdot h_{participate} + W_{el,calls} \cdot (p_{EP} - \overline{p_{EPEX}})$$

Negative reserve power:

$$Revenue = p_{CP} \cdot h_{particate} + W_{el,calls} \cdot (\overline{p_{EPEX}} - p_{EP})$$

Note that energy and capacity prices for positive and negative are different and also vary within the day. A distribution of bidding price and likelihood to be accepted and called is used to calculate the revenues. It was constructed from an analysis of prices for capacity and work at the reserve markets. At each point in the year the highest prices that have been accepted for capacity have been filtered out. The same has been done for the energy price. It is assumed that the found probability distributions are constant over the year. The distributions are used to calculate the number of successful tenders and calls, for a given bidding strategy.

Calculation of revenues is done recursively and is shown in Fig. 1.

In a first step, the offered price for energy is determined. The offered price determines the energy bought or sold in each time slice, when participating in the market.

In the second step the price bid for capacity is placed such that the needed electricity can be purchased at the reserve market or that there is sufficient “free” time to supply the electricity from the spot market.

It is clear that only the electricity that is actually required by a heat pump system can be capitalised at the market. It is further assumed that the HP units are available max. 4500 hours yearly for participation on the reserve power market.

Two bidding strategies are implemented to estimate the range of revenues.

Assumptions: Low value: suboptimal CP & EP, 50% annual el. demand brought to market
High value: optimal BIDS, 100% annual el. demand brought to market if possible

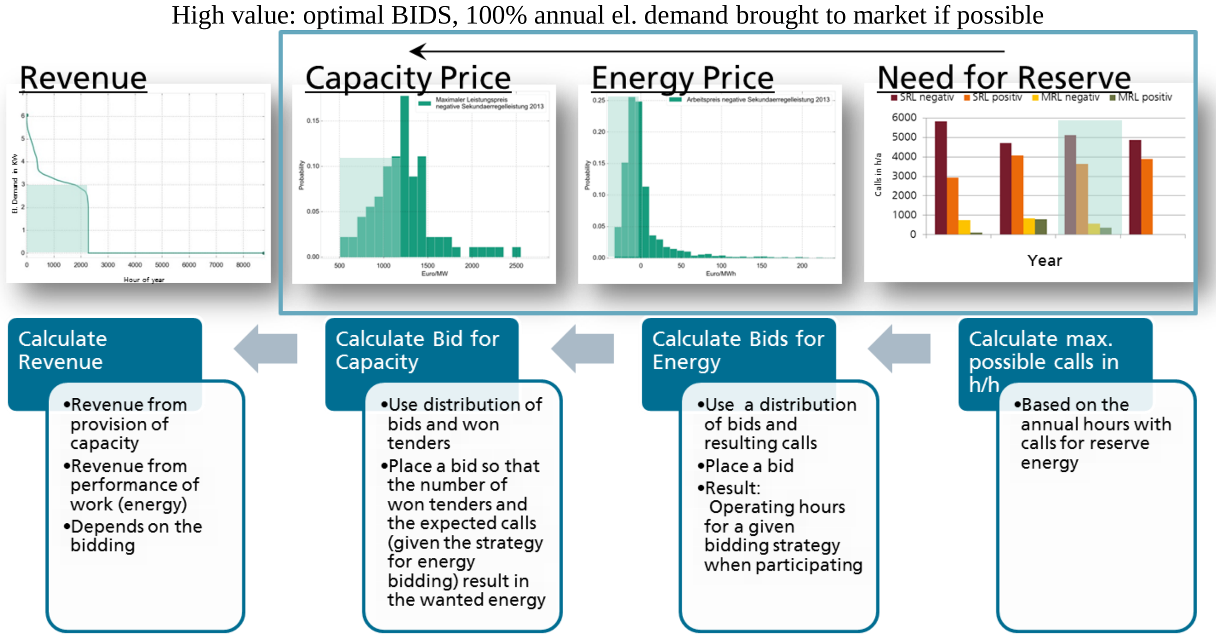

Fig. 1. Calculation of the revenues at the secondary and tertiary reserve markets.

2.2.3. Reduced need for balancing energy

Heat pumps can be used to compensate energy forecast errors in the balancing group. Thus, the purchase of balancing energy is reduced. It is assumed that only a certain proportion of the annual HP electricity demand can be used for balancing.

The realisable revenue depends on the price spreads for balancing energy occurring during the course of the day and the share $\Delta W_{el,WP}$ of needed energy $W_{el,WP}$ that can be used in a high costs time interval to reduce forecast errors. This change in operation is compensated during low cost times, leading to a consecutive forecast error. The distribution of the daily price difference between high and low prices for balancing energy is used to quantify the potential monetary gain when shifting operation. For this purpose the daily 0.25 and 0.75 percentiles ($p_{EPEX,q25}$, $p_{EPEX,q75}$) for balancing energy prices for 2015 are used. Revenue is calculated to:

$$Revenue = \overline{p_{el,BE}} \cdot \overline{\Delta W_{el,WP}} \cdot W_{el,WP}$$

Assumptions [5], [6]: Low value $\overline{\Delta W_{el,WP}}$: 15% of annual HP electricity demand
High value $\overline{\Delta W_{el,WP}}$: 60% of annual HP electricity demand

Price difference: 6.4 ct/kWh, based on the mean quartiles difference (25/75) of balancing energy price 2015.

2.2.4. Optimised electricity purchase at the spot market

Shifting electricity consumption towards favourable times at the electricity spot market allows a reduction of the electricity purchasing costs. The realisable revenue depends on the price spreads occurring during the course of the day and the share $\Delta W_{el,WP}$ of needed energy $W_{el,WP}$ that can be shifted from a high to a lower costs time interval. The distribution of the daily price difference between high and low prices at the day-ahead spot market for electricity (EPEX) is used to quantify the potential monetary gain when shifting operation. For this purpose the daily 0.25 and 0.75 percentiles ($p_{EPEX,q25}$, $p_{EPEX,q75}$) in spot prices for 2015 are used.

Revenue through optimized procurement on EPEX is calculated as follows:

$$Revenue = (p_{EPEX,q75} - p_{EPEX,q25}) \cdot \overline{\Delta W_{el,WP}} \cdot W_{el,WP}$$

Assumptions [5], [6]: Low value $\overline{\Delta W_{el,WP}}$: 15% of annual HP electricity demand shifted from high to low
High value $\overline{\Delta W_{el,WP}}$: 60% of annual HP electricity demand shifted from high to low

Price difference: 1.3 ct/kWh, based on the mean quartiles difference (25/75) of EPEX Day-Ahead 2015.

2.2.5. Improved efficiency

Weather forecasts, analysis of operational data and sophisticated control algorithms can be used to increase the efficiency of heat pump systems by optimally using available control options and storage potential. In order to calculate the revenue of this business model, the efficiency gains $\Delta Efficiency$ are multiplied with the electricity price $p_{el,WP}$ and the annual electricity consumption $W_{el,WP}$.

Possible efficiency gains are stated to 5% [7], up to >35% in the case of office buildings [8]. The revenue from increasing the energy efficiency is given by:

$$Revenue = \Delta Efficiency \cdot p_{el,WP} \cdot W_{el,WP}$$

Assumptions: Low value: 5% Efficiency gains
High value: 20% Efficiency gains

2.2.6. Increased PV self-consumption

By adapting the controls of the heat pump, PV self-consumption can be increased. This leads to a reduced need for electricity from the grid, but also to a reduced feed-in to the grid. According to literature a self-consumption increase of 10% to 40% [9], [10] can be achieved using heat pumps and thermal storage for German conditions. The revenue from increased self-consumption is calculated as the difference of the electricity buying price ($p_{el,WP}$) and the feed-in tariff ($p_{el,EEG\ PV}$) multiplied with the increased self-consumption ΔSC and the produced PV electricity $W_{el,PV}$.

$$Revenue = \Delta SC \cdot (p_{el,WP} - p_{el,EEG\ PV}) \cdot W_{el,PV}$$

Assumptions: Low value: 10% Increased self-consumption
High value: 40% Increased self-consumption

2.2.7. Reduced grid fees

The possibility to shut down the heat pump by the operator of the electricity distribution system lets the heat pump become a interruptible load (ENWG § 14a), enabling the grid operator to reduce the network charges by max. 80% (StromNEV §19 Abs. 2 S. 1). The resulting revenue is calculated using:

$$Revenue = \Delta gridfee \cdot p_{el,grid} \cdot W_{el,WP}$$

Assumptions: Low value: 20% reduction
High value: 80% reduction

2.2.8. Reduced concession fees

If heat pump operation can be shifted towards hours of low grid loads, using a two zone tariff scheme, concession fees may be reduced during low price hours (see KAV §2.7). Assuming 50% of the demand during low price hours the revenues are calculated to:

$$Revenue = \; 0.5 \cdot (\, p_{conc,normal} - \; p_{conc,low\ load}) \cdot W_{el,WP}$$

Assumptions: Low value: concession fee <25,000 citizens 1.32 ct/kWh
High value: concession fee >500,000 citizens 2.39 ct/kWh
Concession fee during low load hours: 0.61 ct/kWh

Table 3. Summary of the methodology, assumption and value ranges used for estimating revenues.

	Energy		**Price**	
	Upper value	**Lower value**	**Upper value**	**Lower value**
Primary Res.			Mean price for capacity	
Secondary Res. POS				
Secondary Res. NEG	100% of annual el. demand	50% of annual el. demand	Optimised bidding*	Suboptimal bidding**
Tertiary Res. POS				
Tertiary Res. NEG				
Balancing energy Buying at spot market	60% of annual el. demand	15% of annual el. demand	Mean daily price spread high/low (q75/q25)	
PV self-consumption	Self-consumption +10%	Self-consumption +40%	Difference feed-in to HP tariff	
Efficiency	Efficiency +5%	Efficiency +20%	HP tariff	
Reduced Grid fees	100% of annual el. demand		20% grid fee	80% grid fee
Reduced Concession	50% of annual el. demand		Community > 500 000	Community < 25 000

*Revenue from capacity and energy bids is maximised and 100% of the HP energy is brought to market. Pricing assumption is based on price distribution curve for the given market in 2015.
** Revenue from capacity and energy bids is chosen to lie in the average and 50% of the HP energy is brought to market. Pricing assumption is based on price distribution curve for the given market in 2015.

3. Results

This section presents the results for the qualitative and quantitative business model analyses.

3.1. Qualitative analyses: Business model canvas

The investigated business models target different customers. The most important ones are grid operators, balancing group authorities, traders and heat pump operators. All business models have to be beneficial for the heat pump owner, so that he offers his heat pump for contracting. The benefits have to over compensate the expected losses resulting from contracting. These could be loss in indoor comfort or increased electricity consumption due to a loss in efficiency. Value proposition, resulting from flexible heat pump operation differs depending on the business model. Among these could be reduced costs for heat, fixed additional revenue, reduced use of natural resources, reduced CO_2 emissions or reduced costs for grid operation. It is clear that the main actors, proposed values and resulting revenue streams depend on the chosen business model. A key activity in all business models is the control of the heat pump unit. This can be done either by direct control or by sending incentive signals (like prices). Signals can be sent in real time or ahead of time. Information on the state of the heat pump, the storage and the building, as well as the current state of the power grid, market prices and forecasts can play an important role for the chosen control approaches depending on the business model. In order to operate heat pumps in the electricity market (spot or reserve) a minimum offer in the size of several MWs is required for direct participation. Consequently, the pooling of several units is needed for most of the business models. Furthermore, these markets require licences and certification, which add additional complexity to these business cases.

Key resources for the contractor to operate the heat pump in a flexible way are a metering platform, communication interfaces, control concepts and algorithms and the human resources needed to handle complexity and operation. The main costs result from communication technology, possible efficiency losses, administration and market fees. Key partners for the flexibility contractor are technology providers, like heat pump manufacturers, ICT providers, software companies and energy traders. System planners influence the potential flexibility of heat pump systems through design and sizing decisions. Table 4 presents the key indicators according to the Business Model Canvas method for the various business cases.

Table 4. Business model canvas for the different cases.

	Optimised purchasing at the spot market	**Reducing balancing energy**	**Reserve markets**	**Reduced grid fees and concession**	**PV self-consumption (local)**	**Efficiency (local)**
Customers	Electricity retailer or utility, energy trader	Balancing Group Responsible	Transmission System Operator	Distribution System Operator	End-customer with HP&PV	End-customer with HP
Value Proposition	Reduced costs for electricity purchase	Balancing of forecast errors, reduced need for balancing power and thus payments	Additional capacity in the market, reduced costs for balancing power	Better use of grid, congestion management, avoided grid reinforcement	Reduced el. costs for HP, autarky, less CO_2 emissions	Reduced el. costs for HP, improved HP lifetime, less CO_2 emissions
Channels	Fairs, direct contact	Internet, fairs, direct contact	Public access	Internet, fairs, direct contact	Internet, fairs, direct contact	Internet, fairs, direct contact
Customer Relationship	Personal, automated service	Personal, automated service	Automated service	Personal, automated service	Personal, web-service, hotline	Personal, web-service, hotline
Revenue Streams	Price difference wholesale retail, change in long term contracts, use of price fluctuations, arbitrage	Less money spent for balancing	Capacity payments, payments for provided energy	Reduction of grid fees, reduced costs for grid reinforcement, reduced concession fees	Price difference between feed-in tariff and HP tariff	Energy and thus cost savings
Key Resources	Market admission, market experience, control devices, ICT, algorithms	Control devices, ICT, algorithms	Prequalification of devices, ICT, market admission, control devices	Control devices, ICT	Measurement and control devices, ICT	Measurement and control devices, ICT
Key Activities	Read data, controls, forecasting, trading	Read data, controls, forecasting	Controls, forecasting availability of HP, market bidding	Read data, controls	Read data, controls	Read data, controls, forecasting
Key Partners	Technology provider, system planners, market providers	Technology provider, system planners	Technology provider, system planners	Technology provider, system planners	PV plant operators, technology provider, system planners	EMS operators, technology provider, system planners
Cost Structure	Market admission, ICT, trading, billing, efficiency losses	ICT, Billing, efficiency losses	Prequalification , market admission, ICT, trading, billing, efficiency losses	ICT, efficiency losses	ICT, Billing, efficiency losses	ICT, billing

3.2. Estimated revenue potential

Profits to be distributed amongst the parties have to be generated for the success of a business model. Within this study the revenue potential of each business model has been estimated for a German single family house. Costs have been neglected in this part of the analyses but are discussed in Section 3.3 and should be calculated in future work.

Figure 3 shows the range of estimated revenues for the different business cases. It can be seen that the revenue for the different cases varies considerably from approx. 10 €/$kW_{HP,el}$/a up to more than 120 €/$kW_{HP,el}$/a. When operating on the reserve markets primary reserve yields the highest revenues followed by negative and positive secondary reserve. Providing services to the balance group in terms of reduced costs for balancing energy yields revenues up to approx. 85 €/$kW_{HP,el}$/a, making it a comparably attractive option. Optimising electricity purchase price due to operation on the spot market yields relatively small revenues, as spot market prices are low (and are falling continuously). Business models targeting an improvement of onsite PV self-consumption or HP efficiency, yield relatively high results. This emerges, since each kWh saved is multiplied with the end-customer prices for electricity or its difference to the feed-in tariff. Furthermore, improved efficiency is in effect for the total purchased electricity over the year. The same holds for reduced grid fees and concession fees, which have to be paid for each kWh electricity supplied from the grid. This fact and the relatively high specific costs for grid fees and concession fees lead to high revenues for those business models. Moreover, those two revenues can be easily combined. Note that this is mostly already included in today's HP tariffs, consisting of low and high price windows. Combining different business models is possible and can further increase the revenue, but also increases complexity. Please note that the estimations presented were done with simplified assumptions and will be done in more detail in future research.

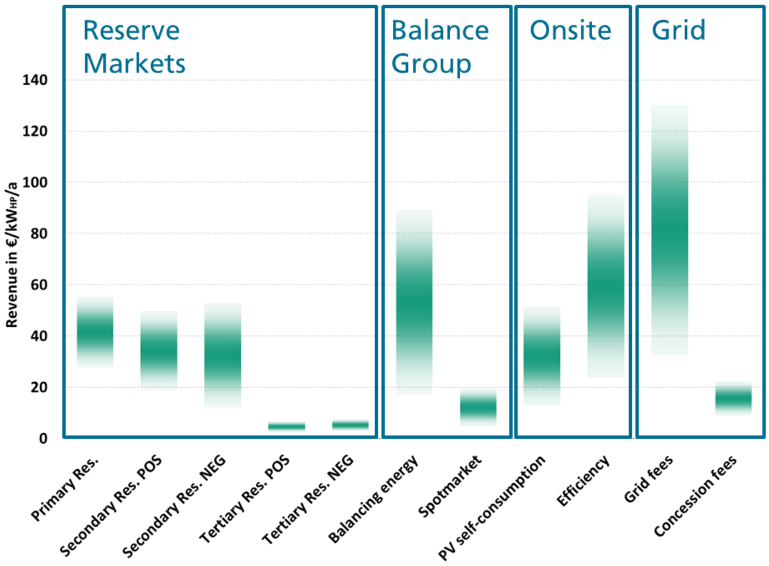

Fig. 2 Estimation of revenue potential of the individual business models per kWel HP and year.

3.3. Technical considerations

Besides the revenue potential, which is shown in Figure 2, costs, technical requirements and possible risks should be considered as well. Table 5 highlights these aspects in a reduced form. The following statements can be concluded:

- Pooling is needed in order to achieve the minimum capacity for market participation and is further recommended profit from the economies of scale. For the local business models, pooling is not required but contracting and controlling a large number of plants will add economies of scale.
- When contracting the flexibility of heat pumps it must be guaranteed that the required heat is available in the building at all times and that the comfort requirements of the dwellers are fulfilled. Otherwise reputation of the contractor and acceptance of new business models are in danger.
- Depending on the case, different needs for flexibility and different technical requirements for the heat pump, storage and communication device arise.
- It should be considered that heat pump flexibility is not constant over the year and depends on system design parameters such as storage and heat pump size, implemented controls and the thermal load.
- The business models with high revenue potential and low complexity (PV self-consumption and reduced grid fees) are already present at the market.
- The business models targeting on efficiency increase of heat pumps are attractive and comparably simple to realise. Hence, these are expected to be established soon.
- Purchasing electricity at the spot market does not show high revenue potential. However, compared to the participation in the reserve markets, this implies lower risks, lower technical requirements and market complexity.
- Reacting to forecast errors and reducing the need for balancing power seems economically attractive. However it is questionable if it is possible in in reality to profit from the daily variations in price spread as assumed in this study. A complexity of operation in the recent years has been that inaccurate forecasts could lead to monetary gains. This was the case when forecast error was in line with what was needed in the power system. Currently regulations move towards penalising all forecast errors.

Compared to the timescales and prequalification requirements needed for the provision of reserve power this model seems more attractive.

- Participating in the reserve market implies high risks due to the need for guaranteed availability. This requires skills in prediction and controls to handle the required reliability. These reliability requirements will lead to defensive bidding strategies, which conversely generate less revenue. Furthermore prequalification of the technical units leads to additional costs and complexity.
- From a technical point of view of a single heat pump unit, the market for primary and secondary reserve is little attractive as frequent changes in operation are required. The calculated revenue potential does not seem to justify the technical stress to the system. However, in a large pool frequent switching can be avoided at the cost of lower revenues.
- The market for primary reserve yields the highest revenue potential of the different reserve markets, but it also requires the fastest response (30 s). Weekly tenders add additional risk and complexity.
- The market for secondary reserve seems technically reasonable (ramping time of 5 min). However the operation regime has to be tailored to avoid frequent switching. The revenue potential seems moderate and in recent years, a drop in prices has been observed. Weekly tenders and provision windows of 12 hours add additional risk and complexity.
- The market for tertiary reserve seems most favourable from the point of view of prequalification requirements (15 Minutes time for ramping). Also daily tenders and a provision period of 4 hours seem favourable. The downside of this model is low revenues, mainly caused by the few hours where negative and positive tertiary reserve has been called (ca. 240 hours and ca. 400 hours).

3.4. Bottlenecks

Different factors negatively influence the rise of business models using heat pump flexibility. High shares of taxes and fees at the end customer electricity price reduce the attractiveness of most business models targeting on reducing electricity purchase prices.

Currently most of the heat pumps that are deployed in the field come without or with limited connectivity. Thus, in order to enable heat pumps to be used by a third party, a communication device and also a metering platform have to be installed, which comes at additional cost. Moreover, reliable algorithms for managing and controlling heat pump pools and optimising single heat pump units need to be developed and deployed in commercially available products. Forecasting of heat demand and available flexibility for a pool over a period of several days is hard and error-prone. Hence, the risk participating in the reserve markets, where reliable capacity is required for periods of up to a week, is high. Changing the market towards shorter period tenders would help heat pumps to provide reserve capacity. Also the requirement of having a minimum capacity, which is mostly around 5MW [11], is an obstacle for aggregators focussing on small distributed resources.

Table 5. Attractiveness of the investigated business models divided into technical, costs, revenue and risk aspects.

	Purchase	Grid services and balance group management							Renewables and Efficiency	
	Spot market	Reduced Need for Balancing Power	PR	SR NEG	SR POS	TR NEG	TR POS	Reduced Grid Fees	PV self-consumption	Efficiency
Tech-nical	Timescales suitable for HP	Suitable for HP, though frequent switching has to be avoided	Danger of frequent switching if not taken care of by pool manage-ment	Suitable for HP, though frequent switching has to be avoided		Suitable for HP, though frequent switching has to be avoided, long calls might be problematic		HP suitable already today	Suitable for HP, frequent cycling needs to be avoided	Suitable for HP
Costs	Communi-cation technology, pool management, market participation fees, efficiency losses	Communication technology, pool management, efficiency losses	Communication technology, pool management, market participation fees, prequalification, efficiency losses					Communi-cation and controls	Energy management, efficiency losses	Communi-cation and energy management, efficiency losses
Revenue	low	medium	medium	med ium	med ium	low	low	high	medium	medium
Risk &	low	medium	high	high	high	high	high	low	low	low

Com-plexity								
Attractiveness	medium	medium	low	medium	low	high	high	high

good
moderate
poor

4. Conclusion

Heat pump flexibility can play a major role to enable a transition towards a renewable heat and electricity sector. In order to use this flexibility, new business models and players on the market implementing those are needed. It has been shown that under current market conditions there is little incentive in terms of additional revenue for using HP in the different markets or on the level of a balance unit, compared to already existing business models that merely focus on improving local conditions or exploiting grid regulations. The alternatives that will lead to a full "smart" integration of heat pumps into a future energy system are more complex and risky. Nevertheless additional revenue can be achieved with these models. These business models would profit from facilitated market conditions and the possibility to combine them with the current regulations of reduced grid and concession fees.

All business cases require the connectivity of the heat pump unit, tailored controls and considerable know-how of the flexibility aggregator. Strategic partnerships between the players in the power sector, heat pump manufacturers and heat pump operators will be beneficial for a successful use of heat pump flexibility. The role of the flexibility aggregator could be taken by several players that are currently present in the power system, but could also be taken by heat pump manufacturers as they have access to and knowledge about the heat pump units.

Based on the insights presented in this study, the following recommendations for further action are given to enable an optimal integration of heat pumps in the future energy system: For all the business models investigated in this study, detailed simulations should be done to yield more accurate results for revenue and correctly respecting market requirements and the possibility to simultaneously act on different markets. Moreover, their implementation should be further investigated in collaboration with all the respective actors involved with focus on costs as well as contractual, fiscal and regulatory aspects.

The presented analyses highlights that technical aspects are crucial for a successful implementation of business models for flexibility. Communication devices, control and forecasting algorithms have to be further developed and should find their way from research into practice. Furthermore the influence of changed operating conditions should be studied in detail to quantify possible losses and a reduction in unit lifetime. System sizing, controls and system layout should be studied in detail to enable recommendations for a future heat pump system design that enables more flexibility.

Acknowledgements

The research leading to these results was developed within the "WPsmart im Bestand" project financed by the German Ministry of Economics and Energy (BMWi). We thank Friederike Rautenberg for her support and Danny Guenther and Jeannette Wapler for the fruitful discussions and generous advice.

References

[1] D. Fischer and H. Madani, "On heat pumps in smart grids: A review," *Renew. Sustain. Energy Rev.*, vol. under re, 2016.

[2] C. Eid, P. Codani, Y. Perez, J. Reneses, and R. Hakvoort, "Managing electric flexibility from Distributed Energy Resources: A review of incentives for market design," *Renew. Sustain. Energy Rev.*, vol. 64, pp. 237–247, 2016.

[3] S. Harbo and B. Biegel, "Contracting flexibility services," *2013 4th IEEE/PES Innov. Smart Grid Technol. Eur. ISGT Eur. 2013*, pp. 1–5, 2013.

[4] A. Osterwalder, Y. Pigneur, A. Smith, and T. Movement, "Business model Generation," 2009.

[5] M. Miara, D. Günther, Z. L. Leitner, and J. Wapler, "Simulation of an Air-to-Water Heat Pump System to Evaluate the Impact of Demand-Side-Management Measures on Efficiency and Load-Shifting Potential," *Energy Technol.*, vol. 2, pp. 90–99, 2014.

[6] D. Fischer, K. B. Lindberg, S. Mueller, E. Wiemken, and B. Wille-haussmann, "Potential for Balancing Wind And Solar Power Using Heat Pump Heating And Cooling Systems," in *Solar Integration Workshop*, 2014, pp. 263–271.

[7] D. Fischer, H. Madani, A. Zottl, and S. Braungart, "GreenHP Deliverable 2.1 – Building Integration Concepts," Freiburg, 2014.

[8] D. Lazos, A. B. Sproul, and M. Kay, "Optimisation of energy management in commercial buildings with weather forecasting inputs: A review," *Renew. Sustain. Energy Rev.*, vol. 39, pp. 587–603, 2014.

[9] D. Fischer, F. Rautenberg, T. Wirtz, B. Wille-Haussmann, and H. Madani, "Smart Meter Enabled Control for Variable Speed Heat Pumps to Increase PV Self-Consumption," *24th IIR Int. Congr. Refrig.*, p. ID:580, 2015.

[10] T. Tjaden, J. Weniger, and V. Quaschning, "Möglichkeiten und Grenzen von Photovoltaik- Wärmepumpen-Systemen zur Erhöhung des Eigenverbrauchs von Solarstrom," no. November, 2013.

[11] VDN, *TransmissionCode 2007 Anhang D2 Teil 1 Unterlagen zur Präqualifikation von Anbietern zur Erbringung von Sekundärregelleistung für die ÜNB*. 2007.