Tapping flexibility potential of decentralized controllable loads for smart markets through aggregation

Mathias Müller, Andreas Zeiselmair, Jorge Pedraza Gómez
Forschungsstelle für Energiewirtschaft e.V. (FfE)
Research Center for Energy Economics
Munich, Germany
mmueller@ffe.de

***Abstract* — Flexibility of decentralized controllable loads face the challenge of a lack of prediction data and missing integration mechanisms in order to provide their flexibility to the grid. FfE developed a smart market platform with a special focus on integrating small flexible systems. Therefore, an aggregation mechanism was developed as described in this paper. Based on an introduction to the platform process and the requirements to an aggregated flexibility offer the derivation of available flexibility by determining statistical simultaneity factors is described. Further different pool formation and aggregation schemes are analyzed. Finally, a case study and critical review leads to the outlook.**

Keywords: flexibility, smart grid, smart market, aggregation, pooling, distribution network, smart market platform, congestion management, heat pumps, simultaneity

I. INTRODUCTION AND MOTIVATION

The increasing number of decentralized renewable energy systems, especially PV, due to the German energy transition but also increasing penetration of new electrical loads like power-to-heat systems or electric vehicles pose a significant impact to distribution grids. Finally, this will increase the possibility of local congestions, especially in the lower grid levels. In consequence, new tools and coordination processes are needed to avoid congestions in advance. One effective solution can be the utilization of flexibility options available close to and therefore with an impact on the congestion. Currently, there are only limited possibilities of accessing this relevant potential of available flexibility in the distribution grid [1].

Smart markets that can exploit available flexibility in the grid and allocate it for the use by grid operators in a market-based manner for congestion management is one possible solution. Within the project C/sells, FfE develops the Altdorfer Flexmarkt (ALF) as an implementation of a smart market platform. ALF allocates flexibility offers by available flexibility options (i.e. flexible energy systems) and flexibility demands resulting in predicted congestions by grid operators.

The platform considers two different types of flexibility offers: schedule offers and long-term contraction. With schedule offers, it lies in the responsibility of the operator of the flexibility option to assess its available flexibility and place it as an offer on the platform. Long-term contraction especially addresses small decentralized systems that do not have the possibility of professional marketing, like flexible loads in private households. [2] Nevertheless, these, in particular, can have a relevant impact especially in the lower voltage levels. FfE already visualized this potential within the publication of the “Flex-Atlas”. [3], [4]

In order to tap the relevant flexibility potential, it is essential to find a way to access these small controllable systems that are located in the affected grid parts as automated as possible. Therefore, a process of aggregating and predicting their flexible power was developed for the Altdorfer Flexmarkt. The aim is to generate valid and reliable flexibility offers for systems that per se are not able to deliver a prediction themselves. Finally, these need to be made available to the central matching process in a certain format (i.e. arrays of available power for a defined grid-location in steps of 15 minutes).

However, specific predictions of such systems, especially electrical loads like heat pumps, electrical storage heating or electric vehicles is a relevant challenge. To seize the potential, a prediction method must be developed first. [5] The prediction methodology implemented relies on aggregating them into different pools and calculating the simultaneity factor based on historical data. The proposed forecast method takes also into consideration a confidence interval that adds some security to the process. Once the prediction has been conducted, the next step is to create an aggregated flexibility offer at the platform, which takes into account the type of system it belongs to and the locality of the pool. This locality results in an effectiveness evaluation as proposed in [6].

The overall goal of the proposed approach is to determine the effectively available flexible power under consideration of different influencing factors like available power (depending on simultaneity factor, Level of Security (LoS)) and its effectiveness on the congestion. This leads to generating pools as big as possible but as small as necessary under consideration of homogeneous effectiveness values within the pool.

FfE and the project C/sells are funded by the Federal Ministry of Economics and Energy (BMWi) as part of the "Schaufenster intelligente Energie - Digitale Agenda für die Energiewende" (SINTEG) funding program (funding code: 03SIN121).

II. Integration Process

According to the defined platform process of the Altdorfer Flexmarkt, each operator of a flexibility option registers its flexible system at the online platform under the consideration of the actual marketing options (schedule offers and long-term contraction). In the next step, the local DSO assigns this flexibility option to its defined connection point in its grid. This information then allows visualizing its impact on the grid and eventually its effectiveness on resolving potential grid congestions. The effectiveness of the flexibility option strongly depends on the network topology. In the case of equipment overload, the flexibility option must be located "only" behind the congestion. In the event of a voltage band violation, the distance to the transformer and the impedance of the lines influence the effectiveness. [2], [7], [8]

As mentioned, the challenge is the lack of information in order to predict specific technical behavior of each system as these are used stochastically. Nevertheless, there are external factors that influence the behavior on an aggregated level (i.e. day of the week, season, temperature level, etc.). [9], [10], [11]

III. Determination of the Statistical Simultaneity Factors and Derivation of Available Flexibility

As explained in the previous section, a precise prediction for the power consumed by each individual system is unlikely to be made with the information at hand. For this reason, the method approached in this paper aggregates systems of the same flexibility type. After pooling, the simultaneity factor is calculated for different quarter-hours of the day and additional factors influencing the mode of operation. Based on this, a flexibility prediction is derived. The following description focuses on the disengageable potential of heat pumps. The methodology also works for engageable power and other flexibility types.

The aim of this methodology is to predict the minimum electricity consumption of a given number of systems with a defined level of confidence, which is the disengageable power in this case. This derived flexibility shall be provided to the flexibility platform via a lookup table in order to allow a simple application.

As mentioned before, the technique described in this paper needs historical data. Unfortunately, not enough measurement data for heat pumps in the needed resolution and from the project area were available. For this reason, the FfE GridSim distribution network model was used to create several thousand heat pump load profiles for different types of buildings and users. The profiles for these systems consisted of showing the power output of these plants in 15-minute ticks for a whole year. The simulation considers several factors such as the number of persons per household, the size , location and age of the building. [12], [13]

In the following sections, the derivation of this lookup table is explained. Therefore, different combinations of systems are aggregated and analyzed. The process of calculating the simultaneity factors, the flexibility and then the look-up table is shown in Fig. 1.

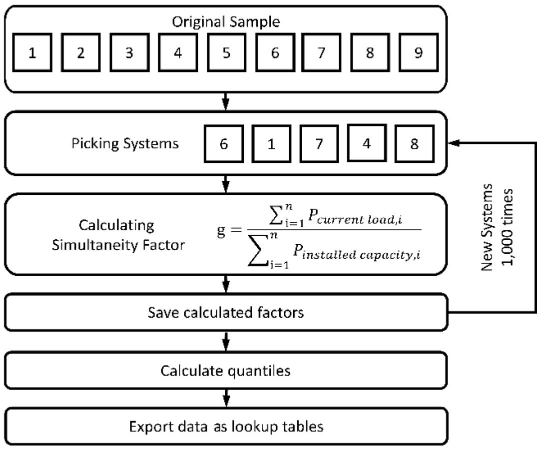

Fig. 1: Method to calculate the simultaneity factors

In the first step from the whole data sample, a number of systems respectively their load profiles are picked (example in Fig 1: five systems). In the second part, for each time step and for each grouping variable, the simultaneity factor g is calculated. For this case, the time step was set to 15 minutes and the grouping variable was the temperature, due to the fact that heat pumps were analyzed. The formula for the calculation of the simultaneity factor can be seen in (1):

$$g(t,T) = \frac{\sum_{i=1}^{n} P_{current\ load,i}(t,T)}{\sum_{i=1}^{n} P_{installed\ capacity,i}} \quad (1)$$

where

g	*simultaneity factor*
t	*time*
T	*(equivalent daily mean) temperature*
$P_{current\ load}$	*power of one system for the given time*
$P_{installed\ capacity}$	*maximum power of one system*

This factor sets the actual power in relation to the installed power and is between 0 and 1. 0 means that no power is currently required and 1 means that all systems are operating at maximum power. The used temperature for the grouping variable is the equivalent daily mean temperature which is also used by grid operators to calculate standard load profiles for heat pumps [11]. For this temperature, the temperatures of the last days are taken into account. This temperature is used because houses are very inert and not only the current temperature is relevant for heating, but also that of the last days. Moreover, most of the heating systems and their control systems take the historical temperatures into account. During the analyzed year, which was 2013, the equivalent daily mean temperatures lay between -7 °C and 26 °C. Performing a Tukey-Kramer test with a confidence level of 5 % showed, that six different temperatures where enough to get significant results for the resulting power of the heat pumps /WHF-01 10 /. In the following analyses, the temperatures are summarized in steps of three degrees.

Due to the lack of data on the nominal power for each installed system, the nominal power was assumed the maximum power of a system that had occurred over the period of one year.

In order to find a confidence interval and predict the flexibility potential with a relative degree of security, a bootstrapping method applied to this data was used. The bootstrap method applied uses no replacement on the resampling process, which is repeated 1,000 times. This resampling process results in at least 1,000 data points for every single particular case that needs to be analyzed. With the help of these data points, the probability of a range of values appearing in a specific scenario was calculated.

The whole process is done also for different numbers of systems. In Fig. 2 the quantiles for different temperatures for the simultaneity factor are shown.

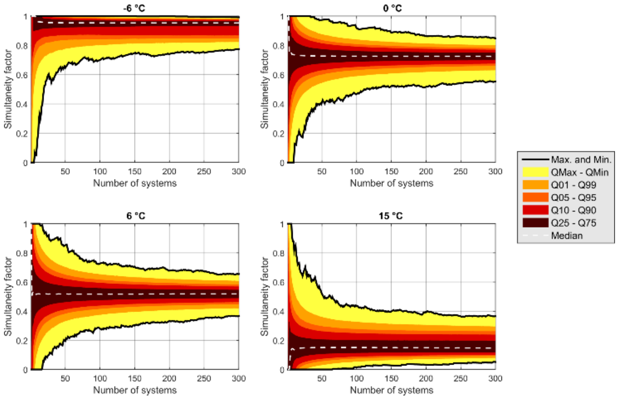

Fig. 2: Quantiles of the simultaneity factors for different temperatures and numbers of systems at 7:00 AM ([14])

The simultaneity factor is higher at low temperatures since there is more demand for heating. The mean simultaneity for -6 °C is over 0.9 (top left) and for 15 °C it is below 0.2 (bottom right). The figure shows also that for only few systems the range of the simultaneity factor is very broad. The more systems are taken into account the smaller the variation of the quantiles get. For only a few systems the simultaneity factor varies between one and zero but gets more and more stable with an increasing number of systems, the maximum variation at 100 systems is at about 0.4. This is also shown in Fig. 3, where the results are displayed for different times and pool sizes.

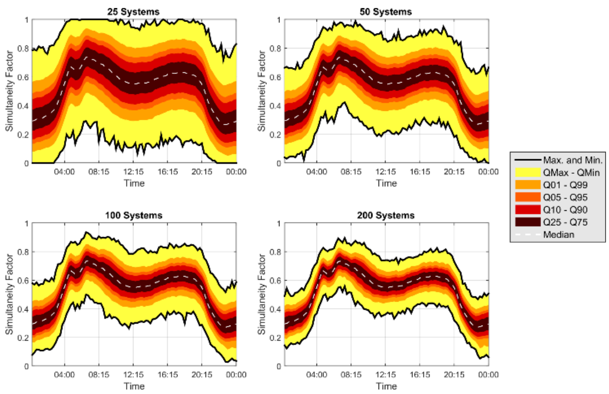

Fig. 3: Quantiles of the simultaneity factors for number of systems and times at 7:00 AM ([14])

It is shown that the difference between the minimum and the maximum simultaneity factor decreases with the number of systems. The profile over the whole day lasts from the heating demand of the houses which is covered by the heat pumps.

Knowing the simultaneity factors and the most important parameters influencing it, it is possible to derive the flexibility of these systems. Relevant parameters in case of heat pumps are time, temperature and number of systems. Flexibility, in this case, means the ability to adjust the actual power of the system. According to the Convention on the Provision of Operating reserve, positive flexibility means, that power consumption is reduced and negative flexibility means, that power consumptions is increased [3]. The following descriptions refer to the provision of negative flexibility. For this purpose, it is necessary to know the simultaneity factor for a specific time, temperature and the number of heat pumps. In addition to that it is possible to set a level of security (LoS), which describes how many times at least this amount of flexibility must be available. Exactly for this purpose, the quantiles were calculated for the simultaneity factor. A level of security of 50 % means that statistically in every second case the available flexibility is lower than needed and in the other cases higher since the value used corresponds exactly to the expected value. If a higher level of security, like 90 % is required, it is necessary to use the 10 % quantile instead of the median of the calculated simultaneity factor. In this case, in 90 % of the time, the available flexibility is above the required one and only in 10 % percent it is below, assuming a symmetrical distribution. In Fig. 4 the difference between the relevant simultaneity factor is shown.

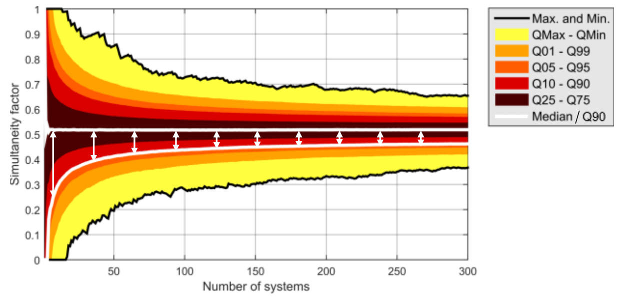

Fig. 4: Difference of the simultaneity factor for different levels of security (50 % and 90 %) for different numbers of systems at 6 °C at 7 AM ([14])

By increasing the level of security, the flexibility potential decreases. The flexibility, i.e. the available power, is then calculated via (2)

$$P_{av} = g \cdot P \cdot n \quad (2)$$

where

P_{av}	*available power on kW*
g	*simultaneity factor (t, T, n, LoS)*
P	*average power of all the systems in kW*
n	*number of systems*

To gain a better understanding of the different impact factors like temperature, time of the day and number of systems, Fig. 5 shows the simultaneity factor at a LoS of 90 % and the resulting available power.

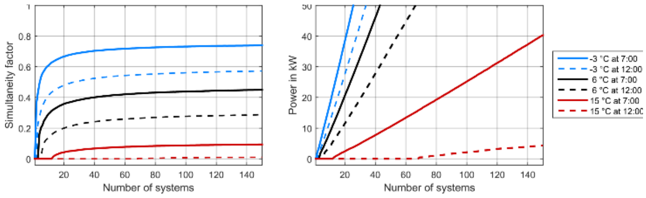

Fig. 5: Simultaneity factor for different number of systems at different times and temperatures (left) and its resulting available power (right) at a LoS of 90 % ([14])

In the last step, the data of the simultaneity calculation is converted to a lookup table, which is put on the smart market platform. The platform then can use this data to calculate the flexibility based on temperature prognosis and the time of the grid congestion. In the next section, different methods to determine an appropriate pool size are described.

IV. Pool formation and aggregation

Applying the procedure defined in section III it is now possible to statistically determine available flexible power of a pool of systems of the same type at a certain level of security depending on relevant external factors. The next step is the integration of this information for the use in the platform process, i.e. defining the pool formation and therefore the relevant level of aggregation in a grid perspective.

Defining the level of aggregation, it is necessary to consider several requirements and correlations:

1. Increasing the pool size reduces statistical uncertainties.
2. The systems in the pool should have rather homogenous effectiveness fators.
3. The aggregation process should be comprehensible and traceable.

This finally leads to a conflict of interests as in general the larger the pool, the higher the simultaneity factor, but the more inconsistent the effectiveness factors of the pool. Another upcoming question is whether a partial call of the pool is necessary. There are two possibilities:

Always calling the entire pool provides the advantage that there is no minimum number of systems necessary per pool. On the other hand, it poses the risk of too much power in relation to the demand for big pools. Therefore, the pools should not be too big. For the calculation process the simultaneity factor can simply be called from the look-up-table as a function of the number of systems (*n*), temperature (*T*) and time of the day (*t*).

Providing a partial call of the pool allows more precise matching. This means that in case that only a part of the power that is available by the pool is demanded, only part of the systems in the pool will be addressed. On the other hand, it demands a fixed simultaneity factor based on a minimum number of systems, which leads to a linearization of the available power graph, illustrated in formula (3). Fig. 6 shows an exemplary result of a linearized power curve. This linearization is necessary since the matching on the flexibility platform is done via a linear optimization. Due to this, the fixed simultaneity factor is usually underestimating the available capacity. Nevertheless, the methodology also works with large pools, since the simultaneity is converging to the median power with increasing numbers of systems.

$$P_{av} = g_{const} \cdot P \cdot n_{partial} \quad (3)$$

where

P_{av}	*available power on kW*
g_{const}	*constant simultaneity factor (t, T, n_{min}, LoS)*
P	*average power of all the systems in kW*
$n_{partial}$	*number of systems called in the range of [n_{min}; n_{Pool}]*
n_{min}	*minimum number of necessary systems (t, T)*

Linearization demands a minimum pool size n_{min}. In order to determine this number different approaches are possible. These are explained and compared in [14].

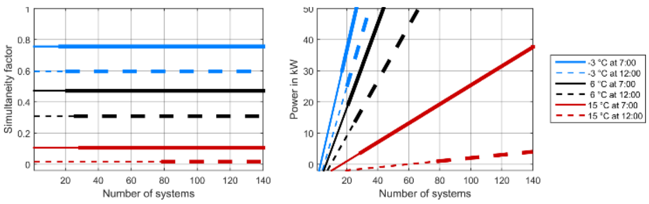

Fig. 6: Exemplary result of a fixed simultaneity factor and the corresponding linearized power curve ([14])

In practical means, the necessity of partial call-off is finally dependent on the pool size or the available power of the pool respectively.

Regarding the level of aggregation the following different methods have been determined – all providing advantages but also certain requirements and drawbacks:

1. Based on grid topology:
   a. Static aggregation at the local grid transformer level represents a simple and comprehensive method. The number of systems per pool tends to be low which then can lead to high uncertainties. A partial call-off would be less necessary due to little available power per pool.
   b. Static aggregation at defined points in grid topology (switches, strings, load areas, etc.) can be restrictet to a minimum number of systems. The addressable spots of congestion move up hierarchically depending on the number of available systems.

   These two approaches do not require information regarding congestion but of the grid structure. The aggregation point determines the pool's effectiveness factor.

2. Based on effectiveness evaluation:
   a. Dynamic formation of groups of low voltage grids with similar effectiveness evaluation is done until a minimum number of systems per pool is reached. Partial call-off is therefore possible.
   b. Arbitrary pooling of systems with similar effectiveness evaluation would also be possible. The chosen pool effectiveness can be uniform for the

entire pool (e.g. minimum or average effectiveness of the pool is used for the whole pool). This can lead to a significant underestimation of the pool's effectiveness.

Approaches based on effectiveness evaluation only work for individual demands and therefore need information regarding the congestion.

Fig. 7 illustrates these different aggregation methods based on exemplary grid congestion and Table I shows a the differentiation of these in a qualitative manner.

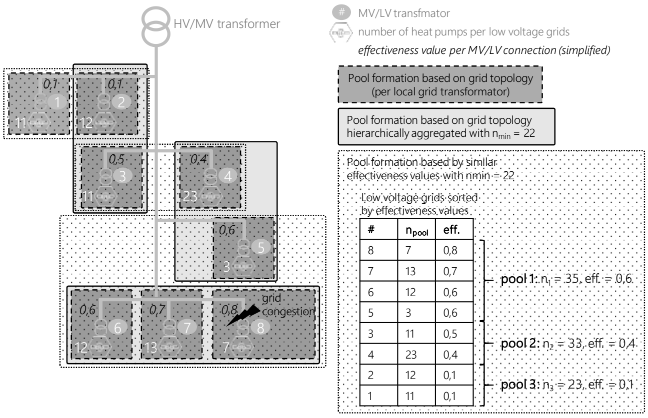

Fig. 7: Illustration of different aggregation methods based on exemplary grid congestion, i.e. pool formation based on grid topology per local grid transformer (1a.) or hierarchically aggregated with $n_{min} = 22$ (1b.) and pooling of low voltage grids based by similar effectiveness values with $n_{min} = 22$ (2a.)

TABLE I. QUALITATIVE OVERVIEW OF SUGGESTED AGGREGATION METHODS

Aggregation method	***1a.***	***1b.***	***2a.***	***2b.***
information on congestion necessary	*no*	*no*	*yes*	*yes*
pool size	*tends to be little*	*sufficient*	*sufficient*	*sufficient*
minimum pool size	*not necessary*	*yes*	*yes*	*yes*
effectiveness	*homo-genous*	*possibly hetero-genous*	*rather homo-genous*	*rather homo-genous*
partial call-off	*no*	*no*	*yes*	*yes*
accuracy of intended power	*low for small pools*	*ok, increases with pool size*	*tends to under-estimate*	*tends to under-estimate*
complexity	*low*	*medium*	*high*	*high*

Besides the scientific analysis of these different approaches, there will also be an implementation and live operation of the Altdorfer Flexmarkt including the proposed integration of decentral flexibility options. Therefore, an evaluation of the different pros and cons for the aggregation method in the demonstration lead to the decision that static aggregation at the local grid transformer level is the most practicable solution. This approach was finally realized and it now tested under consideration of different scenarios.

V. CASE STUDY

In the following section, the methods are applied exemplarily for the C/sells project region in Altdorf, where the flexibility platform is demonstrated. In order to be able to carry out realistic analyses, data and information about the project region, which is powered by one HV/MV transformer, were provided. In total there are 173 local grid transformers, ten of which will be investigated in detail. Today there are only 36 heat pumps connected to these ten low-voltage grids. Future scenarios show high expansion so that 50 % of the buildings are heated with heat pumps; therefore 176 heat pumps are expected. [15]

For the further case study, five typical plant numbers per local grid transformer were selected to determine the flexible power available through the described procedure. The pool sizes are 7, 15, 22, 28 and 67. In Fig. 8 the resulting available power over one year depending on the pool size for the 10 and the 25 % quantil, which means LoS 90 and 75 % is shown.

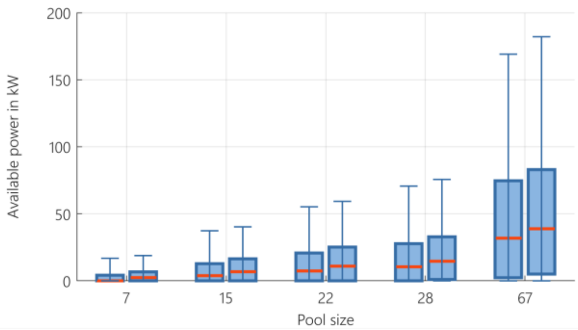

Fig. 8: Resulting available power over one year depending on pool size for LoS 90 % (left bars) and 75 % (right bars)

Fig. 8 illustrates that over one year the average available power is quite low and varies from 2.3 – 48.3 kW (red lines) since there were 81 days with temperatures above 15 °C (wherein for common houses heating is not necessary) [16]. The box shows all values which occurred in 25 – 75 % of the cases. In these cases, the maximum available power for the different pool sizes ranges from 4.2 to 82.9 kW. The whiskers show all values that occurred during one year.

To sum this up, this figure shows, that there is only relevant power available if the pool size is big or the temperature is quite low. However, as shown in the previous section the effectivity must be taken into account as well.

VI. CRITICAL REVIEW

The described approach has shown that the availability of flexibility by small decentralized systems can be predicted through an aggregation model. Nevertheless, there are some challenges on the way. The shown prediction method is, due to a lack of available historical data, based on synthetic data and therefore, there is a risk of having too similar profiles. In addition, until now it is not possible to challenge the forecast method with measured values. The suggested approach for tapping the flexibility of decentral systems only works in normal, temperature-driven operating modes. If the plants are actively marketed or operated based on other signals, such as excess PV, the presented methodology does not work.

The pooling of the systems which is shown in this paper is very crucial for the whole method. If the flex options should not be used to solve local congestions but provide system services, which means that the effectiveness is the same for big pool sizes, then bigger pools are more beneficial due to higher simultaneity factors which lead to a higher available power.

Another challenge is to take into account the technical restrictions of each system. So the flexible capacity, for example, is dependent on the size of the warm water tank of the heat pump. However, as there is already an existing process defined by § 14a EnWG of accessing current flexibility – even if limited in its effectiveness – these preconditions can be used as a common basis. In practice, this means that there are already technical requirements legally defined that controllable loads need to fulfill in order to provide their flexibility. [1]

VII. Summary and Outlook

The described approach to tap the flexibility potential of decentralized controllable loads for smart markets through aggregation shows one method to forecast the flexible power of heat pumps as flexibility options. By analyzing their simultaneity factor the available switchable power of heat pumps is determined. In the first step parameters that have influence on the simultaneity factor like temperature and time of the day were identified. In the second step the simultaneity factors were calculated and different aggregation methods were discussed since there is a conflict of goals between the pool size and the effectiveness of the pool to solve local congestions. The optimal pool size, therefore, depends on the type of congestion or provided service.

Furthermore, it is possible not only to determine the disengageable but also the engageable power with this method. In this case, instead of the 10 % quantile, the 90 % quantile must be used. In addition to that, it must be verified if the heat pumps are able to start working and heating up the house or a boiler. One possible technical solution is to use heat pumps that fulfill the “smart grid ready” standard, which means, that they can be forced to heat.

Despite heat pumps, the whole process also works for other flexibility options like electrical storage heating and potentially also electric vehicles. In case of electric vehicles other parameters, like the type of day are necessary instead of temperature. For this case more research is needed.

In order to efficiently integrate these decentral systems and to provide an incentive to the operators of the flexibility options, appropriate compensation models need to be developed. These have to address the interests of the operators and the needs of the grid operators as the demand side but also consider effects on the energy system.

In the next step, the described method is tested at the Altdorfer Flexmarkt. Another aspect there is the technical proof of how to access to flexibility options in a smart grid by using the (certified) smart meter infrastructure.

REFERENCES

[1] Zeiselmair, Andreas et al.: Erschließung von Kleinanlagen nach § 14a EnWG zur Flexibilitätsvermarktung. In: et - Energiewirtschaftliche Tagesfragen 03/2019. Essen: etv Energieverlag GmbH, 2019.

[2] Zeiselmair, Andreas et al.: Netzdienlicher Handel als Element des zellulären Energiesystems am Beispiel des Altdorfer Flexmarkts (ALF) - 11. Internationale Energiewirtschaftstagung (IEWT). Wien: Technische Universität Wien, 2019.

[3] Müller, Mathias et al.: Regionales Flexibilitäts-Potenzial dezentraler Anlagen - Modellierung und Bewertung des regionalen Flexibilitäts-Potenzials von dezentralen Flexibilitäts-Typen im Verteilnetz. Berlin: Conexio GmbH, 2019.

[4] Müller, Mathias et al.: Dezentrale Flexibilität für lokale Netzdienstleistungen - Eine Einordnung des Flexibilitätsbegriffs als Grundlage für die Konzipierung einer Flexibilitätsplattform in C/sells. In: BWK - Das Energie-Fachmagazin 6/2018. Düsseldorf: Verein Deutscher Ingenieure (VDI), 2018.

[5] Flexibility and Aggregation - Requirements for their interaction in the market. Brussels - Belgium: The Union of the Electricity Industry - EURELECTRIC, 2014.

[6] Estermann, Thomas et al.: Approach to determine the effect of local flexibility options within the framework of a smart market platform in: 8th Solar Integration Workshop. Stockholm: Energynautics GmbH, 2018.

[7] Zeiselmair, Andreas et al.: Altdorfer Flexmarkt (ALF) - Konzeptbeschreibung, Zielsetzung, Funktionsweise und Prozesse des Altdorfer Flexmarkts. München: Forschungsstelle für Energiewirtschaft e.V., 2018.

[8] Köppl, Simon et al.: Altdorfer Flexmarkt – Decentral flexibility for distribution networks. In: Internationaler ETG-Kongress 2019. Esslingen: VDE ETG, 2019.

[9] Cremer, Jochen L. et al.: Optimal Scheduling of Heat Pumps for Power Peak Shaving and Customers Thermal Comfort. Aachen: RWTH Aachen University, 2017.

[10] Hasselmann, Maike: Prognose von Wärmelastgängen - Entwicklung und Analyse eines selbstlernenden Wärmelastgangprognosemodells auf Basis Künstlicher Neuronaler Netze. Dissertation. Herausgegeben durch Ruhr Universität Bochum, geprüft von Doetsch, Christian und Weidner, Eckhard: Bochum, 2017.

[11] Fünfgeld, Christian et al.: Bestimmung von Lastprofilen für unterbrechbare Verbrauchseinrichtungen. Cottbus: Energieressourcen-Institut e.V., 2002.

[12] Kleinertz, Britta; Gallet, Marc; Müller, Mathias; Samweber, Florian; Schmid, Tobias: Load Shifting Potential of Household Power-to-Heat Devices Employing Thermal Storage in: 11th International Renewable Energy Storage Conference (IRES 2017). Bonn: EUROSOLAR e.V., 2017

[13] Köppl, Simon; Samweber, Florian; Bruckmeier, Andreas; Böing, Felix; Hinterstocker, Michael; Kleinertz, Britta; Konetschny, Claudia; Müller, Mathias; Schmid, Tobias; Zeiselmair, Andreas: Projekt MONA 2030: Grundlage für die Bewertung von Netzoptimierenden Maßnahmen - Teilbericht Basisdaten. München: Forschungsstelle für Energiewirtschaft e.V. (FfE), 2017

[14] Pedraza Gomez, Jorge: Availability Forecasts for the Development of Decentralized Flexibility Options. Masterarbeit. Herausgegeben durch die Technische Universität München, betreut durch die Forschungsstelle für Energiewirtschaft e. V.: München, 2019.

[15] Wohlschlager, Daniela et al.: Bottom-up-Szenarien am Beispiel des Altdorfer Flexmarkts. In: ew - Magazin für Energiewirtschaft 3/2019. Berlin: EW Medien und Kongresse GmbH, 2019.

[16] Beitzke, Dietrich: Die Heizgrenze in: http://www.heizungsbetrieb.de/de/heizgrenze.html (abgerufen am 08.09.2016). Archived by WebCite® at http://www.webcitation.org/6kNND9NxY. Aachen: Beitzke, 2016