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G01 International Collaboration

G03 Flexibility Provision & Exchange I

G04 Flexibility Provision & Exchange II

G05 Advanced Technologies Providing Flexibility

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Foreword

The regularly published statistics about the European energy mix and imports from Eurostat[1] shows, that the mix in 2020 consisted of 34.5% of oil and petroleum products, 23.7% of natural gas, 12.7% of nuclear energy, 10.5% of solid fossil fuels and only 17.4% of renewables. The EU dependency on energy imports is sinking, but with 57.5% still is very high. The Ukraine war demonstrates how critical such a great dependence from not trustworthy and unreliable suppliers is. It should be understandable by now that the expansion of locally produced renewable energy serves not only to protect the environment and the global climate, but also to ensure security of supply and political sovereignty. It is no longer only a prediction of the International Energy Agency that locally produced renewable energies have to grow significantly, but also a political and economic demand to realize this change now and on a large scale.
Such developments represent a significant reduction in CO_2 emissions, while at the same time easily stored carriers become replaced with inflexible and geographically as well as temporally unevenly available alternatives. This reorientation generates new and more complex requirements to keep the existing electric power system stable, and requires a new level of capacity and flexibility, both short-term and seasonal, at regional, national and international levels.

From July 4-5, 2022, around 60 experts from industry, government and academia discussed for the sixth time the impact, perspectives and solutions of grid services for a changing power system. With 11 scientific papers and 13 invited presentations, the symposium addressed future market developments, international cooperation, operation and new enabling technologies and flexibility-creating solutions.

The full program of invited and scientific contributions can be downloaded at www.GridServiceMarket.com. The scientific contributions were, among others:
Different electricity market designs; Flexibility shares in low voltage grids; Market attractiveness of fuel cell CHPs; Grid services with electrolysers; Systemic market view, Support for grids with battery vehicles, smart grids and additional flexibility; Real-time pricing; … see all in the table of contents.

Since Corona has influenced the way people met, the symposium was a hybrid event, with physical present attendees networking traditionally and virtual attendees with remote access. All the presentations are streamed and on-demand available on www.GridServiceMarket.com/MemberZone.

Below you will find the proceedings of the scientific contributions of GSM 2022 , which we kindly invite you to read.

Sincerely

Prof. Christoph Imboden	Dr. Michael Spirig
HSLU	EFCF

[1] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=EU_energy_mix_and_import_dependency

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A specially formed **International Advisory Board (IAB)** assured constant high quality and a strong focus on industry challenges. The members of the IAB are:

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International Collaboration

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G0105

Comparison of European electricity market designs

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Abstract

The energy system is changing with the expansion of renewable energies. This structural change requires flexibility. This flexibility can be provided by small-scall flexible assets. However, the expansion of large quantities of small-scall flexible assets can only be realized based on profitable business models. Therefore, new marketing strategies for small-scale flexible assets are needed. On the one hand, this challenge is valid for the whole of Europe. On the other hand, marketing strategies are often explicitly developed only for a single country. Although there are efforts to create a common electricity market, the markets are rather different in detail due to the different conditions in each country (composition of generation and demand, history etc.). This leads to the research question, whether it is possible to transfer marketing strategies designed in Germany to other countries. To address this question, in this work, a holistic comparison of the different electricity market designs in Europe is performed.

For this purpose, the following methodology is applied: first, the system boundaries – both geographical and market design boundaries – are defined. This is followed by the identification of key figures to describe the market mechanisms of the different European market designs. In the last step, the differences between the market design of several European countries are compared to the German market design.
The geographical boundaries are based on the borders of the European Union, the membership of the power exchanges in the NEMO-Committee and is extended by the countries United Kingdom and Switzerland due to their central location and political relevance. In addition, smaller countries are pooled, resulting in 26 regions. In total 5 market mechanisms are considered: spot markets, forward markets, balancing services, existence of capacity mechanism and number of bidding zones. The market mechanisms are specified with in total 19 different key figures.

As a result, the countries Italy, Ireland, Spain, the United Kingdom, and the Czech Republic show the highest deviations from the German market design. The high rating can be derived mainly from the large (e.g. Italy) or small (e.g. Czech Republic) variety of trading products on the respective markets. In particular, the characteristics of balancing energy are the most influential factor when comparing the countries with each other.

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Introduction

In the course of the decarbonization of the energy, sector constant fossil generation is replaced by volatile renewable energies. This leads to the necessity for flexibility to maintain a stable energy system. On the other side, the electrification of demand as well as ongoing improvements in the area of storage technologies introduces a large number of new flexible assets. To make this flexibility potential available to the energy system, new business models for small-scale flexible assets are currently developed. Yet, these business models depend on the preconditions of electricity markets and the regulatory framework. Thus, for one business model to be transferable to another country, the countries' market design needs to be comparable to a certain degree.

The European Union (EU) aims at establishing "common rules for the generation, transmission, distribution, energy storage and supply of electricity" [1]. Nevertheless, despite the EU single market regulation, there are still clear differences among the electricity markets of European countries [2]. Therefore, this work assesses the characteristics of electricity markets in European countries. It thereby aims to identify the major differences and similarities among the electricity market design of those countries. Electricity market design thereby can be characterized as the organization and distinction of the single market mechanisms [3]. Thus, this work takes a selection of market mechanisms into account and compares certain characteristics of those mechanisms as key figures for relevant European market regions. As a result, the identified differences and similarities of the market designs can be taken as a basis to transfer modeled revenues and costs for small-scale flexible assets from Germany to other European countries.

The methodology of this assessment is explained in the following chapter, describing the three steps of system boundary definition, key figure identification and market design evaluation. In the following chapter, the results of each step are presented. The last chapter draws concluding remarks and indicates possible directions for further research.

1. Methodology

The methodology is split in three parts: defining system boundaries, identifying key figures, and evaluating market design difference value (see Figure 1).

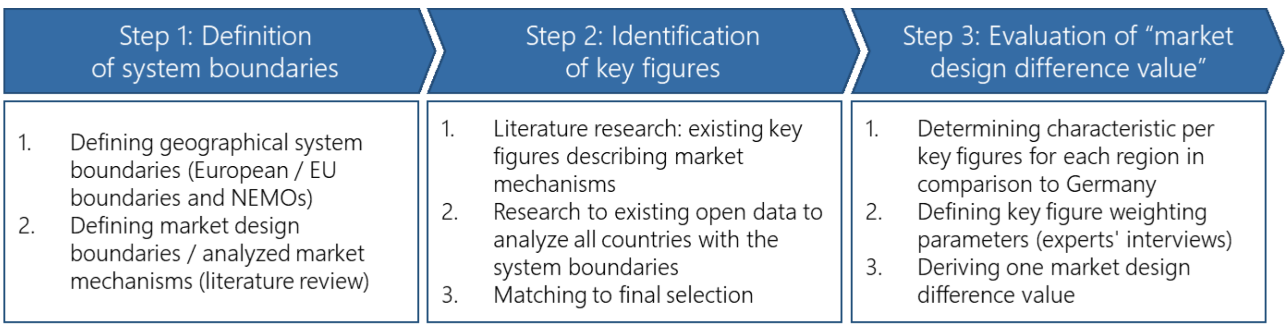

Figure 1 – Methodology

First, the system boundaries are defined. This includes the geographical boundaries as well as the market design boundaries. The geographical boundaries are based on the European/ EU borders and the Nominated Electricity Market Operators (NEMO) operating in Europe. Geographical boundaries were adjusted by the division of the NEMOs areas,

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such that public data availability is included in the boundary definition. Also, country size and economical relevance within Europe is considered leading to countries with lower economical relevance being summarized to one region. The market design boundaries, referring to the market mechanisms analyzed, are determined via a literature review about existing markets in Europe.

The second step is to identify key figures describing the regions' market design. This is performed by a literature review about existing key figures, which is compared with possible open data of the relevant TSOs / NEMOs to determine a final selection of key figures.

The last step is the evaluation of the market design difference value. First, for each market mechanism of each region, a characteristic per key figure is determined. Depending on the difference of the associated characteristic to the same characteristic for Germany, each key figure gets a binary value P_i to show the difference to the German market design. Thus, when a country's characteristic does not differ from the German market design, the key figure is set as 0, and conversely when the characteristic clearly differs, the key figure is set to 1. Due to the varying degrees of impact of the key figures, these binary values P_i can't be summarized uniformly but must be weighted. To derive weighting parameters for each key figure (on each market) W_i, five institute-internal expert interviews are performed. The final weighting parameter is calculated as the mean value of these 5 interview participants, the authors' choice, and a non-weighted solution (to reduce the subjectivity of the interviews). An overall score for each country y is calculated as the sum of the binary values P_i multiplied with the weighting parameters W_i (see EQ. 1):

$$y = \sum_{i=1}^{m} P_i \frac{W_i^{interview\,1} + W_i^{interview\,2} + W_i^{interview\,3} + W_i^{interveiw\,4} + W_i^{interview\,5} + W_i^{author} + 1}{7}, \quad (1)$$

with m as the number of key figures and $\sum W_i = 1$.
This score y provides information on the similarities and differences of the regions' electricity market design compared to Germany.

2. Results

The results are illustrated according to the methodology in 3 steps: definition of the system boundaries, identification of key figures, and evaluating market design difference value.

Step 1: Definition of the system boundaries

In total 26 regions in Europe are considered in this paper, illustrated in Figure 2 with their representative NEMOs. The regions are orientated at countries' borders with some exceptions: the Baltic countries which are considered as one region and Luxembourg and Northern Ireland are integrated in Germany and Ireland, respectively, as each these regions form one united bidding zone. Moreover, the two Danish market areas are analyzed as two separate regions, as they do not only have separate price building, but also different market design characteristics. Thus, the following regions were analyzed: Germany (including Luxembourg), France, Austria, Belgium, Finland, Great Britain (without Northern Ireland), Poland, Italy, Denmark 1 (western part of Denmark), Denmark 2 (eastern part of Denmark), Switzerland, Spain, Portugal, Sweden, Norway, Czech Republic, Netherlands, Ireland (including Northern Ireland) Slovakia, Romania, Hungary, Greece, Bulgaria, Croatia, Slovenia, and the Baltic countries (Latvia, Lithuania, Estonia).

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The following market mechanisms are considered: 2 types of spot markets (day-ahead and intraday), 2 types of forward markets (future and options), and 4 types of balancing energy markets (FCR, aFRR, mFRR and RR). Also, it was evaluated if a capacity mechanism is existent in the considered regions, as well as the number of bidding zones within one region.

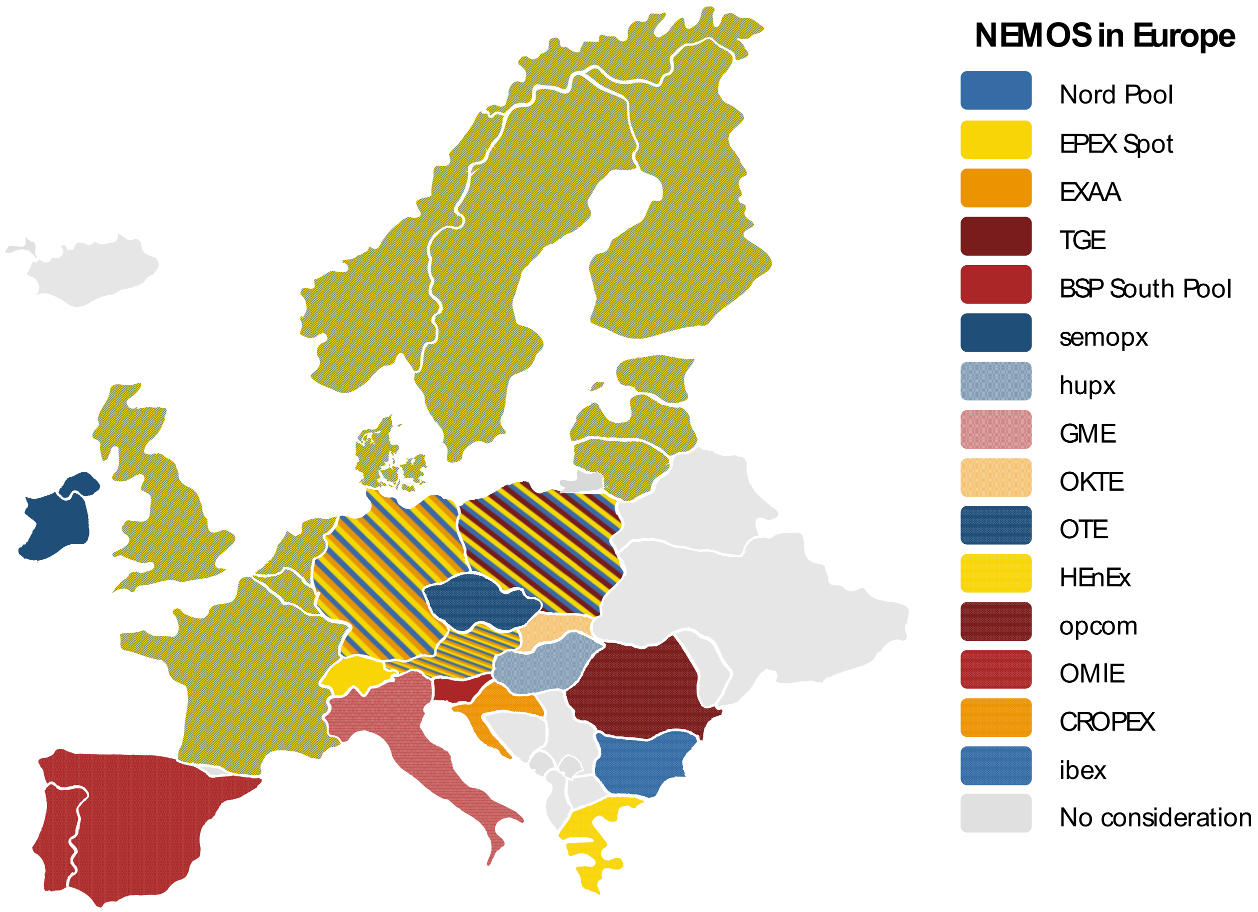

Figure 2 – Geographical system boundaries / considered regions with their respective NEMOs based on [4-21]

Step 2: Identification of key figures

For the identification of key figures, a literature research is performed [3,22,23]. Here, key figures such as prequalification conditions, time between trade and delivery, margin, price cap, pooling of assets, trading time, minimum bid size and transaction costs are mentioned. The key figures found in literature are then compared to publicly provided information by NEMOs and TSOs to obtain a final set of key figures with their characteristics and relevant markets (see Table 1).

Table 1 – Key Figures

Key figure	Market mechanism	Characteristic
Price formation	Spot markets, balancing services, and Forward markets	Spot markets: marginal price and/or pay-as-bid Forward markets: different variants of average price Balancing services: marginal price and/or pay-as-bid and/or regulated price

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Minimum duration of power delivery	Spot markets, balancing services, and Forward markets	Spot markets: 15 min - 60 min, block products Forward markets: daily - yearly Balancing services: 15 sec - 8 h
Market coupling	Spot markets and balancing services	Spot market coupling associations: SIDC Balancing services coupling associations: FCR and/or IGCC and/or Joint Nordic and/or PICASSO and/or MARI
Time period between trade and delivery	Spot markets and balancing services	Spot markets: 0 h - 4 h Balancing services: hourly to yearly
Form of procurement	Spot markets and balancing services	Spot markets: Auction and/or continuous trading Balancing services: market based and/or mandatory and/or hybrid
Fulfilment	Forward markets	Cash settlement/contractual fulfilment
Physical Delivery	Forward markets	None or weekly/monthly
Power Purchase Agreements	Forward markets	0- or 6- or 10-years duration
Cascading futures	Forward markets	Splitting longer time contracts into short time contracts or direct settlement
Planning process	Balancing services	Self-Dispatch Portfolio-Based or Self-Dispatch Unit-Based or Central Dispatch
Asset pooling	Balancing services	Distinction between existent and non-existent
Minimum bid size	Balancing services	0,1 MW - 10 MW
Ramp-up time until full power is provided	Balancing services	10 sec - 120 min
Activation rule	Balancing services	Merit-order, pro rata or combination of merit-order and pro rata
Price range	Spot markets	Classification into two ranges
Number of bidding zones	Bidding zones	1 – 7 zones
Existence of capacity mechanism	Capacity mechanism	Strategic Reserve or Central Buyer or Decentralized Commitment or Targeted Capacity Payment or New Capacity Tender or Energy Only Market (EOM)

Price formation and the minimal duration of power delivery were evaluated for all market mechanisms considered. The other key figures were not evaluated for each mechanism, as they are either not suitable for some of the mechanisms or no data is publicly available. For spot markets and balancing services, additionally it was evaluated if there is market coupling among different regions, the time period between trade and delivery, as well as the respective form of procurement.

Some key figures also refer only to one market mechanism if they reflect an important aspect of it. For forward markets, these are the form of fulfilment (cash or contractual fulfilment), if and for which time periods there exist products with physical delivery, if and

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for which time periods there is a trade of power purchase agreements in the region's forward market and if there is a form of cascading futures. Key figures assessed only for balancing services were the planning process for the dispatch, if there exists a form of asset pooling, the minimum bid size, the ramp-up time until full power is provided as well as the rule for activation. Furthermore, price ranges were classified into two categories as an additional key figure for spot markets.

In addition, two further key figures are introduced: number of bidding zones per country and existing capacity mechanism. As more bidding zones are expected to lead to higher price volatility resulting in higher revenues for flexible assets, the number of bidding zone is also considered as a relevant key figure. In Europe, most countries have one bidding zone with a uniform zonal price. Exceptions are Italy and the Nordic countries Denmark (already split into two regions), Norway, and Sweden. Sweden into four, Norway into five, and Italy into seven zones [13,16]. The countries Germany and Luxembourg as well as Ireland and Northern Ireland – which are considered each as one region in this paper - share one bidding zone [10,21].

As a capacity mechanism influences the liquidity and the mix of technologies in the other markets, the existence of a capacity mechanism was included as an additional key figure. The capacity mechanisms of the relevant regions are illustrated in Figure 3. Of the considered regions, Austria, Denmark, the Netherlands, Switzerland, Slovakia, Hungary, Norway, Estonia, Latvia, Slovenia, Romania and the Czech Republic have so far no capacity mechanism. The most used mechanism in Europe is Central buyer so far. Central buyer is a centralized bidding process, where the assets are paid for the capacity as well as for the provided energy.

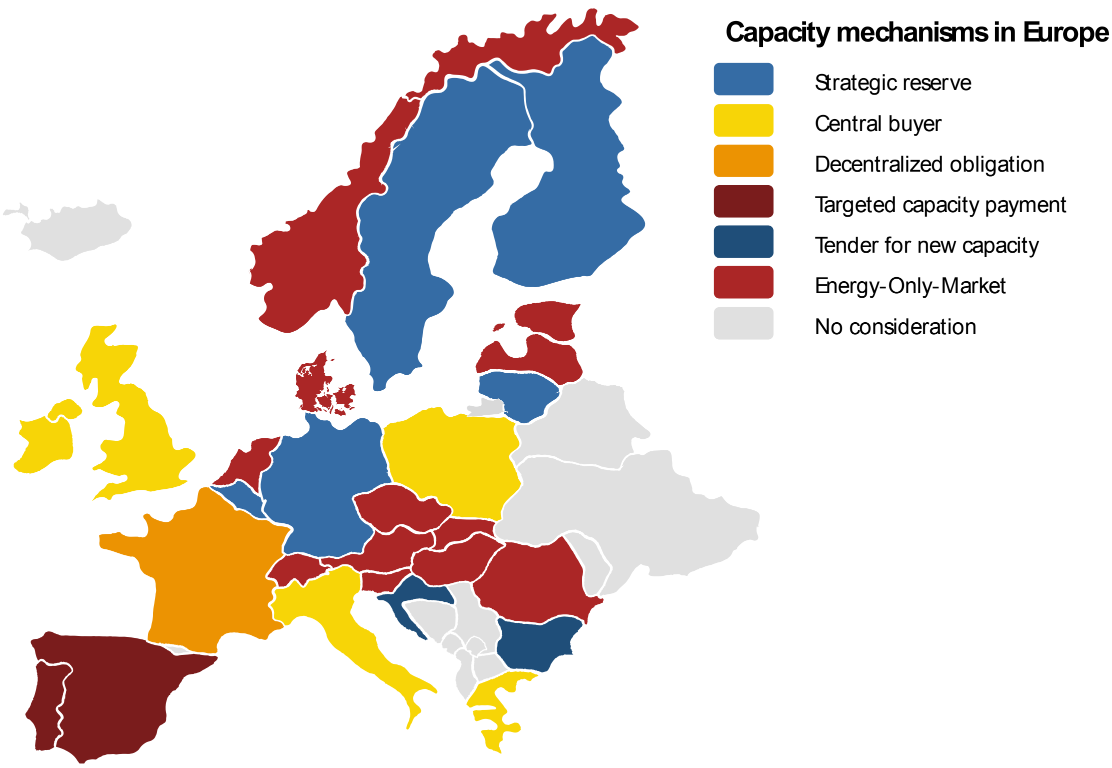

Figure 3 – Capacity mechanism based on [2,23-26]. For Spain, targeted capacity payment is shown even though there is discussion for a new mechanism [27].

The key figures for the different markets plus the two additional key figures lead to 19 key figures. Day-ahead markets where not included into the final comparison, as in the

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considered regions this mechanism was harmonized to an extent that no relevant differences occurred among the selected key figures.

Step 3: Evaluation of market design difference in comparison to German market design

The final result of this paper is the evaluation of the market design difference in comparison to Germany (see Figure 4). Most of the considered regions are already uniformly standardized in many market design features due to the efforts to create a single European market. Nevertheless, there still do remain significant differences. Regions with the highest deviation in comparison to Germany are Italy, Ireland, Great Britain, Spain, and Czech Republic. In opposite, for regions like the Baltic countries, Austria, France, Switzerland, Slovakia, Belgium, Croatia, and the Netherlands, the market design is relatively harmonized with German design.

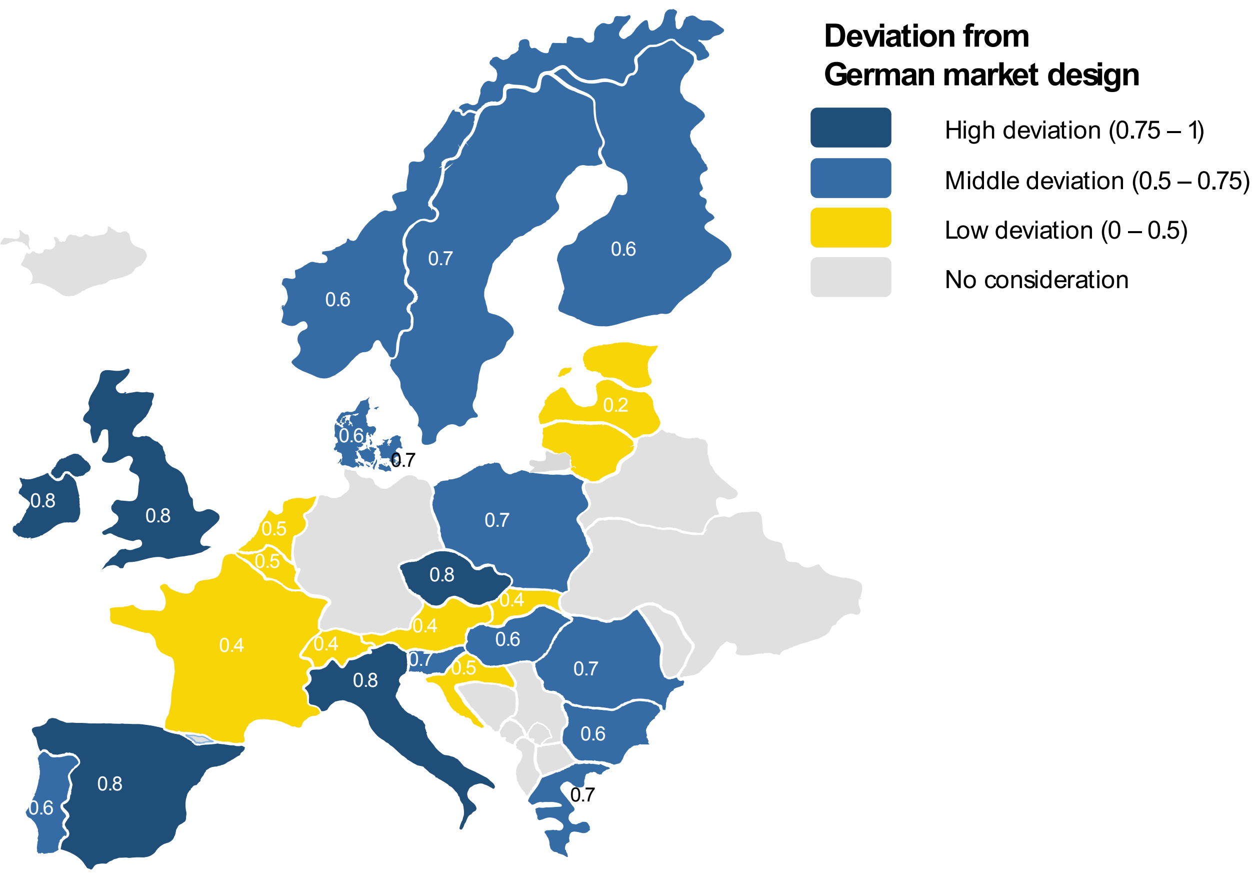

Figure 4 – Deviations in comparison to German market design

Taking a closer look at the high deviation countries, mainly three differentiating aspects can be identified:

1. Low harmonization of balancing services (no market coupling and other product design): more types of FCR (Ireland, Great Britain) or mFRR (Czech Republic) or an existing Replacement Reserve (Great Britain, Italy)
2. More than one bidding zone (Italy)
3. A generally limited market design (Czech Republic)

The differences split into the different market mechanisms are demonstrated in Table 2.

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Table 2 – Deviations per market in comparison to Germany

Region compared to Germany	Bidding zones + capacity mechanism	Intraday market	Balancing services	Forward markets	Overall score
Baltic	0.08	0.00	0.07	0.00	0.15
Belgium	0.00	0.00	0.30	0.17	0.47
Bulgaria	0.08	0.12	0.21	0.15	0.55
Denmark 1	0.08	0.00	0.43	0.10	0.61
Denmark 2	0.08	0.00	0.56	0.10	0.74
Finland	0.00	0.00	0.46	0.10	0.56
France	0.08	0.00	0.28	0.05	0.40
Greece	0.08	0.16	0.28	0.15	0.66
Great Britain	0.08	0.05	0.55	0.10	0.77
Ireland	0.08	0.20	0.53	0.00	0.81
Italy	0.14	0.14	0.46	0.10	0.84
Croatia	0.08	0.15	0.26	0.00	0.48
Netherlands	0.08	0.00	0.33	0.08	0.48
Norway	0.14	0.00	0.34	0.10	0.59
Austria	0.09	0.00	0.11	0.17	0.37
Poland	0.08	0.00	0.43	0.17	0.68
Portugal	0.08	0.15	0.34	0.00	0.57
Rumania	0.08	0.12	0.39	0.15	0.73
Sweden	0.07	0.00	0.49	0.10	0.66
Switzerland	0.08	0.05	0.23	0.08	0.43
Slovakia	0.08	0.00	0.22	0.15	0.44
Slovenia	0.08	0.11	0.32	0.15	0.65
Spain	0.08	0.15	0.48	0.06	0.77
Czech Republic	0.08	0.12	0.46	0.11	0.77
Hungary	0.08	0.10	0.32	0.11	0.61

3. Conclusion

Despite the European Union aiming towards electricity market harmonization, the analysis of European electricity market mechanisms still shows a broad range of variants for the market design. The identification of appropriate key figures and the respective characteristics yet enables to quantify those differences. Thus, in this work we assess the differences of the market mechanisms of spot markets, futures markets, balancing services, as well as the existence of a capacity mechanism and the number of bidding zones. We therefore evaluate the differences within those mechanisms relative to the German market for 26 identified European regions using public data of the relevant NEMOs and TSOs.

Thereby, the spot markets are the most harmonized market mechanism due to the broad participation of the countries in market coupling, while the future markets vary strongly depending on the coordinator responsible in this region. Moreover, also the non-market specific characteristics (the existence of a capacity mechanism and the number of bidding zones) vary among the regions compared.

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The countries with the strongest deviations in market design from the German markets were Italy, Ireland, Spain, the United Kingdom, and the Czech Republic. Here, either a high variety of trading products (e.g., Italy) or a low variety of trading products (e.g., Czech Republic) causes the difference. The highest impact on the evaluation has the market mechanism balancing services due to many considered sub-markets and characteristics. Moreover, also the form of the capacity mechanism and the number of bidding zones chosen by the countries are decisive for the contrasts in the market design.

It should be noted that over-the-counter-trading (OTC trading) was not considered in this paper. However, the exchange of European electricity products takes place predominantly through this form of trading. A further investigation of the characteristics of OTC trading thus can yield valuable insights on the European market harmonization.

Furthermore, the high deviations in the European market design raise the question of how these differences impact business models for small-scale flexible assets. This might be especially relevant for marketing strategies targeting balancing services, as these showed the highest deviations in market design. By this analysis further insights could be derived, which characteristics hinder or which on the other hand enable and incentivize the integration of those assets into electricity markets.

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Flexibility Provision & Exchange I + II

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Flexibility shares in a low-voltage distribution grid: Identification of dimensioning load peaks and characterization of impacted end-customers for flexibility activation as a solution for peak mitigation

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Abstract

Among the issues distribution system operators are anticipating today, the management of peak loads is at the forefront. This problematic has repercussions on the dimensioning of the network infrastructure that must support these peaks, consequence of the deployment of distribution energy resources like solar panels, or the introduction of future consumption needs driven by the electrification of the energy system. In answer to this problematic, leveraging the electrical flexibility of end-customers mixing consumption and production profiles is considered particularly promising to avoid the oversizing of the grid infrastructure or the use of dimensioning cases too strict for connecting new end-customers to the grid.
To determine the flexibility shares the DSOs can use as leeway for the grid management, the end-customers' load profiles made available by the deployment of advance metering infrastructure are leveraged, in combination with the data obtained from the DSOs' geographical and network information systems. Utilizing the deployment of their advance metering infrastructure, Groupe E initiated a data-driven project analyzing the load profiles in a typical low-voltage distribution grid covering 269 distinct end-customers. These end-customers present combinations of profiles mixing baseline residential consumption, particular non-standard consumption (heat pumps, electrical vehicles) and production (photovoltaic) profiles.
Based on this data, a methodology has been proposed to identify critical loci in time and location where the grid infrastructure reaches its load limits and targets select impacted end-customers for the activation of flexibility lowering in return the peaks critical for the infrastructure. The methodology follows a data-oriented approach to (1) identify the flexibility shares in the grid where the activation improves the load on the infrastructure using the load profiles and (2) propose a flexibility controlling strategy benefiting the grid infrastructure with the analysis of the effects of this strategy on the grid infrastructure and the impacted end-customers.

Keywords: electrical flexibility, low voltage distribution grid, advanced metering infrastructure, load profiles, time series

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Introduction

With the expected growth of electrical energy consumption and the changes in power flow directionality in distribution grids, distribution system operators (DSOs) will be more and more confronted with the issue of peak consumption and production loads management. In Switzerland, the national final electrical consumption has stabilized with a +0.6% yearly average rate over the last 30 years with a total of 58TWh consumed in 2021 [1]. However, with the energetical electrification envisioned by the National Energy Strategy and recurrently mentioned by the strategy monitoring, DSOs foresee a rebound of electrical consumption for the coming years [2]. Existing signs of the changes in power flow directionality and electrification are seen today with the installation of new loads such as heat pumps (HP) and electrical vehicles (EV) or the growth of grid-connected solar production installations (PV).

When focusing on recently introduced loads impacting the peaks of power flow in the grid, the yearly rise of between +6% and +8% for HP since 2010 is observed, reaching 378'170 units for 1.4GW of combined electrical energy for [1], and between +30% and +40% for EV since 2010, reaching 70'223 cars in 2021 [3]. Moreover, looking at the evolution in grid-connected PV, a yearly rise between 11% and 28% in the number of installations is seen, for an average yearly rise of 7% in total installed power since 2012 reaching 476MW in 2020 with an average yearly rise of +23% of total energy generated reaching 2.6TWh in 2020 [4]. In either direction, consumption, or production, this new electrical power must somehow transit through the distribution grid, often requiring an upscaling of the infrastructure, especially at the low voltage (LV) level.

However, these new actors offer also new possibilities for their operation and controlling, with remotely interruptible devices that can be controlled by the DSOs or configurable consumption or production scheduling that can be uploaded and updated on the devices. Using these capabilities there is the opportunity to directly act on the end-customers' loads impacting the occurrence of infrequent load peaks that would otherwise require an oversizing of the distribution grid infrastructure. The DSOs aims then to harness and leverage the end-customers' flexibility with the objective of preventing load peaks by interrupting and shifting operable end-customers' loads. The use of this flexibility must however satisfy the technical and social constraints of consumptions and productions in the grid: it is therefore necessary to determine when, where and how much flexibility is available. Similar studies assessing demand flexibility needs and opportunities have been conducted in the recent years by Leiva et al. [5] and Abgobanye et al. [6], showing promising results in activation of flexibility for the operating of distribution grids.

In this project, a method to determine these shares of flexibility in the distribution grid is proposed, using primary DSO-available GIS and NIS (geographical/network information system) data and end-customers' load measurements obtained thanks to recently deployed advanced metering infrastructures (AMI) using smart meters. The chapters in this document cover the following steps: 1) Context, 2) Baseline analysis, 3) Results, 4) Future works, and Conclusion.

1. Context

As planned by the National Energy Strategy, the Swiss DSOs are rolling out the new AMI using smart meters, aiming for a minimum end-customers coverage of 80% by 2027 [7]. Leveraging the installation of this infrastructure as part of proof-of-concept tests by the

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western Switzerland DSO Groupe E conducted in 2021, a candidate LV distribution grid has been selected as suitable for flexibility shares analysis. This chapter describes both the attributes of this environment and the available data used for the project.

1.1 Environment description

The considered LV distribution grid consists of 164 unique service points, supplying 269 unique end-customers divided between 6 separated LV branches, all supplied at the same medium voltage (MV) to LV substation. Using the DSO GIS and NIS data, the service points are described as seen in table Tab.1. This composition shows that the distribution grid is of a highly residential nature, resonating with the flexibility objective of a granular control of the end-consumers' installations to optimize power flow to limit peaks. Moreover, looking at the distribution of controllable power loads, both for consumption like HP and EV and for production like PV, table Tab. 2 sums up the GIS and NIS data.

Both the "Villa" and the "Apartment block" categories are shown to offer sizable amounts of controllable devices, potentially useful for flexibility activation in the grid using HP and PV installations. Despite the EV category only represented by one single user, considering the very residential nature of the grid, the potential growth for EV can be assumed, especially for end-customers in by the "Villa" description.

As part of the AMI deployment, 256 of the 269 unique end-customers were equipped with individual smart meters. The metering coverage is shown in table Tab. 3. There are therefore thanks to the AMI unique load curves available with a 95% penetration rate for this distribution grid. Examples of a more detailed decomposition showing the distribution of HP, EV and PV per customer category is presented in section 3.2.

1.2 Categories of data sourced from the considered environment

Two main categories of data were used within this study: GIS/NIS data and AMI data. As already shown in part, detailed GIS and NIS data is available, informing not only on the characteristics of end-customers but also describing the entire topological construction of the LV grid infrastructure, from the MV to LV substation all the way down to individual service points. Figure Fig. 1 shows the reconstruction of the considered grid, indicating with coloration the 6 different LV branches supplying the end-customers.

Description	Villa	Apartment block	Farmhouse	Public infrastr.
Amount in #	157	5	4	3

Tab. 1 – Distribution of service points by unique categories

Description	Villa		Apartment block		Farmhouse		Public infrastr.	
Amount	*in kW*	*in #*	*in kW*	*in #*	*in kW*	*in #*	*in kW*	*in #*
HP	149	74	102	5	2	1	0	0
EV	17	1	0	0	0	0	0	0
PV	344	43	0	0	0	0	0	0

Tab. 2 – Penetration of consumption and production devices, in power volume and number of devices

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End-customer category	Amount in #	Amount equipped with AMI in #
Villa	163	154
Apartment	71	69
General services (incl. heating)	18	16
Studio	8	8
Others	9	9
TOTAL	**269**	**256**

Tab. 3 – AMI coverage per end-customer category

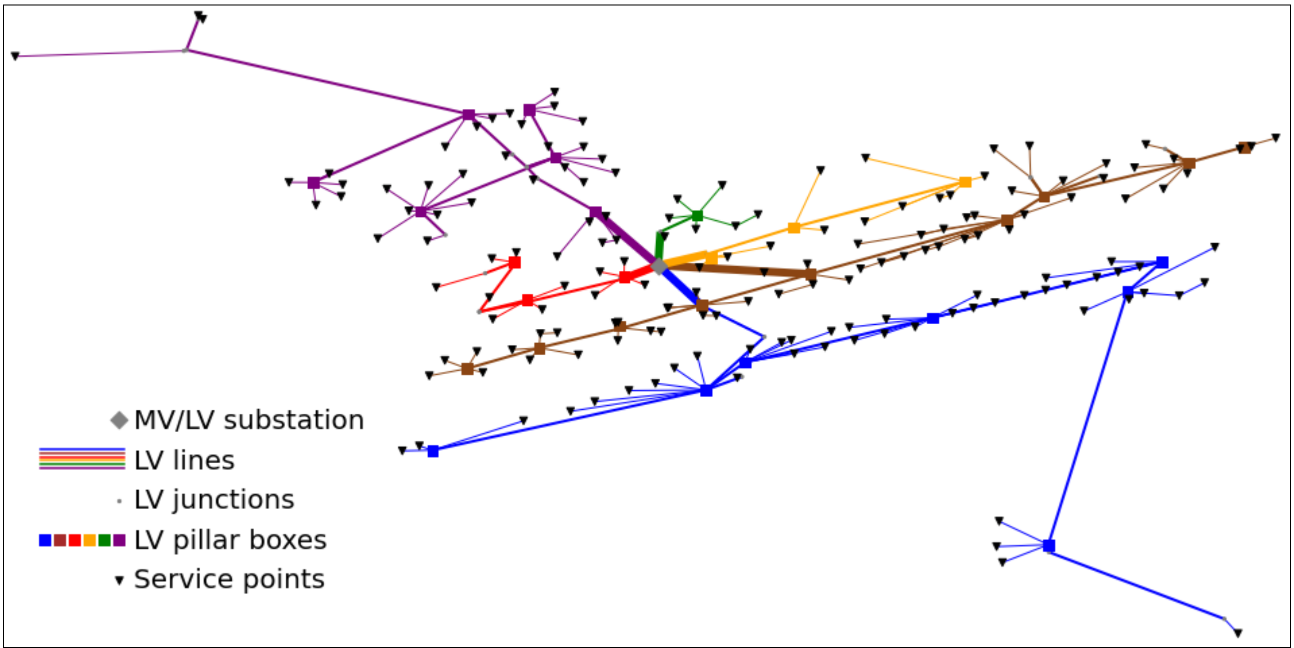

Fig. 1 – Graph representation of the considered distribution grid

Physical quantity	Points of data			
Voltage in V	UL1		UL2	UL3
Current in A	IL1		IL2	IL3
Power in kW, kvar	Pin	Pout	Qin	Qout

Tab. 4 – Points of data available per smart meter

The GIS and NIS data is primarily used for attributing the power loads measured with the AMI, identifying the end-customers' consumption and production and their potentially available devices for flexibility activation, and reaggregating the loads on the LV lines upstream between the service points and the MV to LV substation. The analysis of these power loads is shown below in chapter 2.

The AMI data is available following the smart meters deployment, carried out over the second half of the year 2020. Time series measurements are therefore available for a complete year, taken from 04.01.2021 to 31.12.2021 with 15-minutes intervals, totaling 34'656 unique points of data expected for each of the 259 smart meters. For each metering device, table Tab. 4 shows the surveyed measurements. For each end-customer in the grid, it is therefore possible to follow both the bidirectional power loads measured at meter and the voltage evolution throughout the year.

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2. Baseline analysis

This chapter presents the analysis of the AMI data combined with the GIS/NIS DSO data. These results give an overview of the various possibilities enabled by the availability of voltage and load curves coupled with the precise knowledge of a distribution grid composition and provide the baseline considerations used further for flexibility share identification and flexibility application.

2.1 Voltage measurements at the end-customers'

Using the 3-phase voltage measurements, it is possible to follow the voltage variation for each end-customer. For DSOs, this variation can be a problem to solve in both cases of consumption (voltage fall) and production (voltage rise), as the supplied voltage at the end-customers' is regulated both by norms in application such as the DIN EN 50160 norm [8] and European-wide recommendation such as the D-A-CH-CZ document [9].

Following these rules, DSOs are for example required to guarantee a minimal and maximal voltage variation of ±10% measured at the end-customers'. Before the deployment of AMI, precise measurements closest to the end-customers in the grid could only be done using specialized devices on a per-case basis. Using the AMI, it is now possible to follow the voltage evolution without interruption for each equipped end-customer and perform analysis such as shown in figures Fig. 2 and Fig. 3.

Going back to the 34'656 unique points of data proposed in the previous chapter, the end-customers' voltage evolution in figures Fig. 2 and Fig. 3 show that portions of data are missing for single or multiple days intervals. These gaps are caused by malfunctioning of the AMI, occurring on the side of the metering devices and/or because of temporary downtime of the telecommunication infrastructure used for metering data upload, shortcomings caused by the proof-of-concept nature of the deployment test conducted by the DSO. "Purple spots" occurring seemingly stochastically over the year-range measuring interval are also noticeable, mainly attributed to metering device misreading.

Overall, with this first simple visualization, the following issues impacting the end-customers for the DSO to solve are seen:

1) fall of voltage during the winter season, more so in the middle of the night coinciding with the simultaneous turning on of heaters by telecontrolling[1], in the morning with the end-customers' waking up, and in the evening with the typical residential load.
2) rise of voltage during the summer season, in the middle of the day coinciding with the simultaneous distribution production coming from the PV installations.

These issues occur with the rise of power consumption and production respectively. It is therefore logical to infer that with a reduction of these power loads, if possible, using flexibility activation, voltage differentials will also decrease. The analysis of flexibility activation on the voltage evolution is discussed in more details in chapter 4.

[1] *The DSO Groupe E relies on centralized telecontrol of the residential heating infrastructure for turning on and off commands, carried through the grid infrastructure over a specific frequency. Historically, the turning on commands were set to occur simultaneously in the middle of the night to take advantage of lower energy prices on the energy market, but this practice is progressively leading to voltage drop issues and risks of overloading of the electrical grid infrastructure leading to oversizing of equipment to handle the peak loads.*

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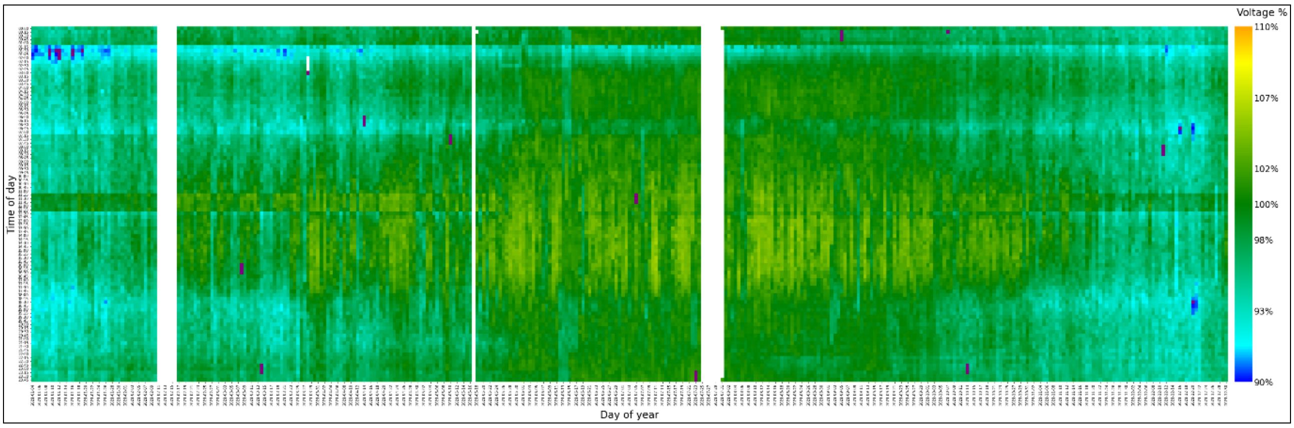

Fig. 2 – Calendar heatmap showing the voltage evolution for an end-customer affected by low voltage falls

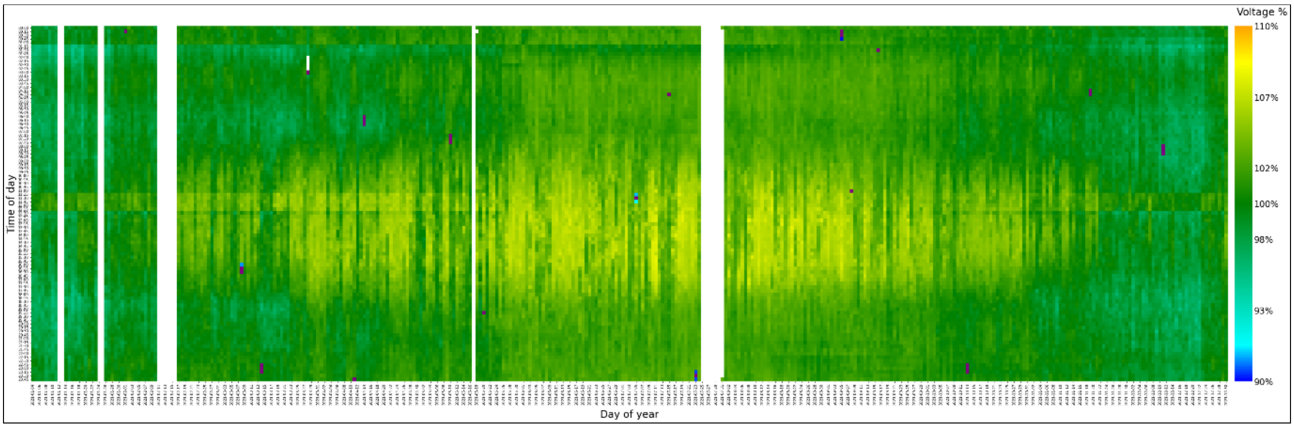

Fig. 3 – Calendar heatmap showing the voltage evolution for an end-customer affected by high voltage rises

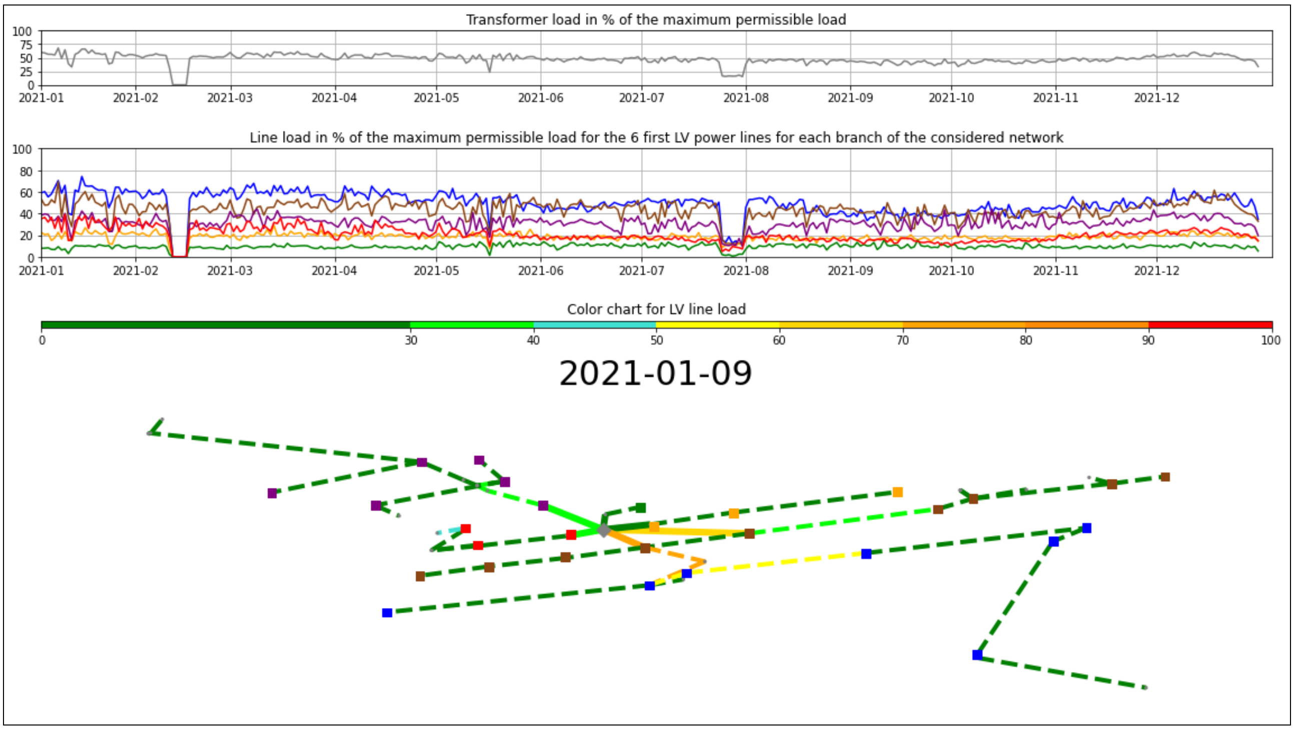

Fig. 4 – Evolution of the maximal measured load per line shown in the distribution grid and the aggregation of values at the MV to LV transformer

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2.2 Topological reconstruction and load attribution

The other main consideration for the DSO is the load of the existing infrastructure, from the MV to LV transformer through the grid power lines and to the end-customers' connection line ("last mile"). Using the power measurements obtained from the AMI, these power loads are mapped to every single one of the 259 equipped end-customers. Then, using the GIS/NIS data, the distribution infrastructure is represented in the form of a topological graph where nodes match the MV to LV substation, LV pilar boxes, LV junctions and service points, and where edges match the LV power lines, as already shown in figure Fig. 1. Using additive backpropagation starting from the service points nodes and going up the LV lines, the corresponding loads per LV line are calculated, as shown in Eq. 1 and Eq. 2:

$$\begin{aligned}&\text{Line topology}: \ \text{Substation} \rightarrow \text{Line } j \rightarrow \text{PB } a \rightarrow \text{Connection line } i \rightarrow \text{Service point } i\\&\text{Power line } j \text{ load}: \ \text{Sum of loads of service points } i\end{aligned} \qquad \text{Eq. 1}$$

$$\begin{aligned}&\text{Service point load: } \mathrm{Load}_{\mathrm{S,i}} = S_i = \sqrt{P_i^2 + Q_i^2}\\&\text{Power line load}: \mathrm{Load}_{\mathrm{I,j}} = I_j \text{ with } S_j = \sum(S_i) = I_j \cdot U_L \cdot 3\end{aligned} \qquad \text{Eq. 2}$$

After computing the individual loads per LV power line, and matching the values with the topological data, the load evolution across the grid over the year-range of available measures is compiled as shown in figure Fig. 4. Again, intervals with missing values are visible similar to what has been observer for figures Fig. 2 and Fig. 3. Nonetheless, some branches undergo higher typical and maximal loads than others, as demonstrated by the "blue" and the "brown" branches shown in figures Fig. 1 and Fig. 4. Based on these results, the next chapter presents a methodology to identify time specific and location specific peak load occurrences to be targeted by flexibility-based load management.

3. Results

Although not all of the objectives of the full "Flexibility Shares in a low-voltage distribution grid" study have been achieved at the time of preparation of this document, the first findings required for the project ambitions can already be discussed. This chapter goes over these results, expanding upon concepts discussed in previous chapters.

3.1 Identification of problematic loci: moment and location of occurrence

As discussed in section 2.2 and shown in figure Fig. 4, the load flows are known for each power line of the considered distribution grid. Using the bidimensional temporal and situational information, the next step calls for the identification of problematic loci where the infrastructure risks overloading. Despite having no critical situations in this grid, it is still possible to look for dimensioning cases, i.e., moments of maximal measured load per line. When focusing on the common grid infrastructure (excluding "last mile" connections), the occurrence of these dimensioning cases can be represented in a calendar map for the 65 remaining power lines as shown in figure Fig. 5.

Clear clusters emerge when looking at the distribution in figure Fig. 5, regrouping occurrences both by time range and by distribution grid branch. The corresponding loci can be determined both algorithmically by clustering analysis and visually by observation.

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Looking into select branches, these clusters appear more clearly, as shown in figure Fig. 6. Based the results displayed here, specific analysis has been done on the “blue” (Fig. 6a) and the “purple” (Fig. 6b) branches.

3.2 Flexibility identification by affected end-customers

Figure Fig. 7 shows the power lines considered as problematic from section 3.1. Unsurprisingly, both branches see the most charged connections on their principal distribution arteries, except for the first segment in the “purple” branch. For these two examples, a detailed description of affected end-customers is provided in table Tab. 5, in order to then identify the potential flexibility technical availability.

From the affected end-customers, the power measurements are then extracted from the AMI data for the relevant timeframes, split into the four categories shown in table Tab. 5 and finally summed per category. When displayed as a function of time, the results can be seen in Fig. 8. Looking at the power evolution, the following can be deduced:

a) The “blue” branch displays a significant peak occurring between 01:00 and 02:00 in the night of the considered interval, driven by the turning on of HP. Looking at the preceding and following hours, it appears that the devices contributing to this peak could have their power consumption distributed by activation of flexibility to smoothen the overall power consumption.

b) The “purple” branch displays its most significant consumption peak 19:00 and 22:00 of the considered interval, typical hours for residential activity. It is interesting to note that in the preceding hours, a peak of PV production can be seen. If the technical and social constraints allow for it, this case presents is promising for an activation of flexibility that could match part of the consumption demand with the production offer in time.

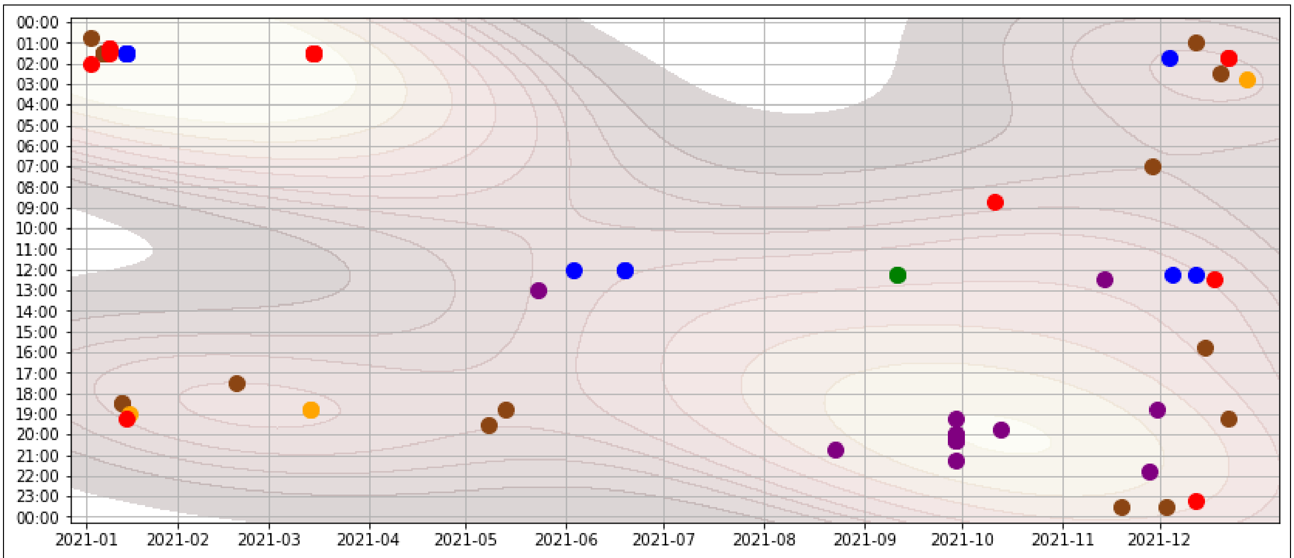

Fig. 5 – Distribution of dimensioning cases for the common grid infrastructure with branch coloration

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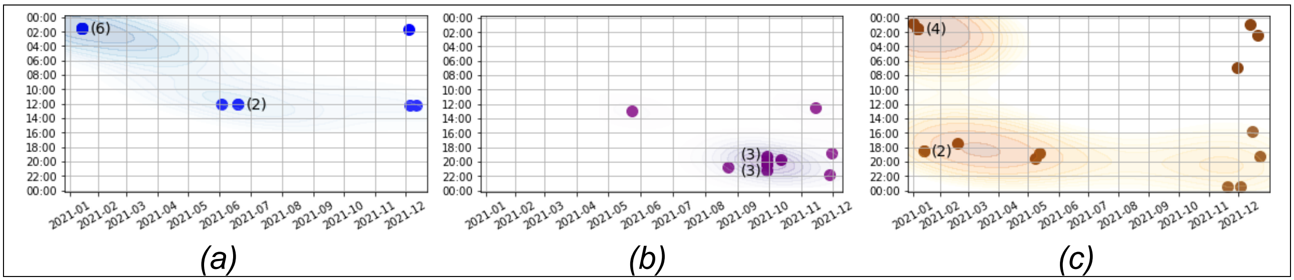

Fig. 6 – Distribution of dimensioning cases for the common grid infrastructure with branch coloration and indication of overlapping points

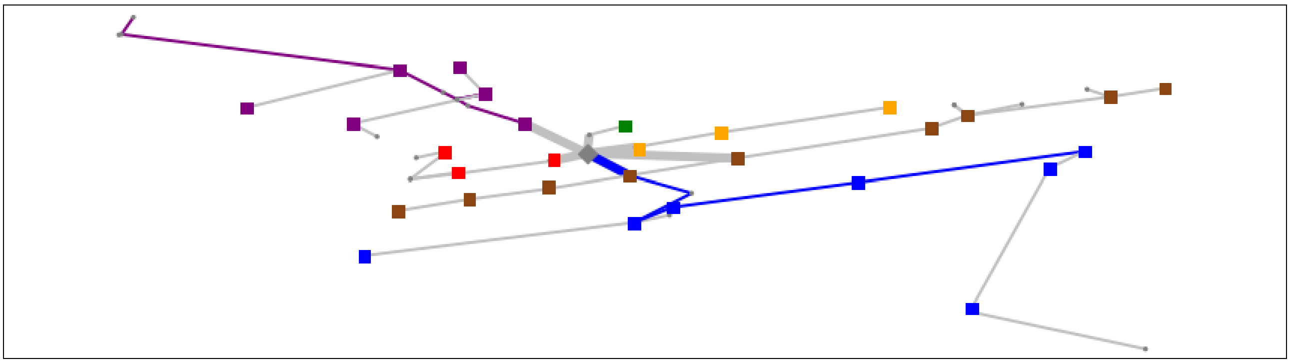

Fig. 7 – Topological graph showing the problematic lines for the considered (colored) and discarded (greyed out) branches

Description		"Standard"	w/ HP	w/ PV	w/ HP&PV	**Total**
Amount in # / %	**Blue**	39 / 52%	25 / 34%	5 / 7%	5 / 7%	**74**
	Purple	32 / 67%	8 / 17%	2 / 4%	6 / 12%	**48**

Tab. 5 – End-customers' characteristics and distribution over both branches

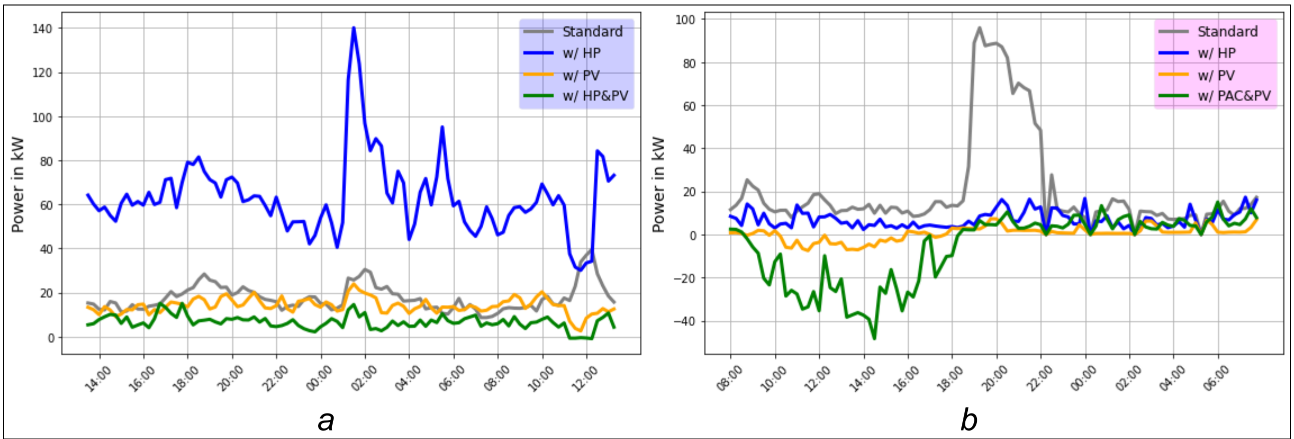

Fig. 8 – Power evolution centered around the dimensioning cases for the "blue" (a) and "purple" (b) branches, for dates 2021-01-16 and 2021-09-29 respectively

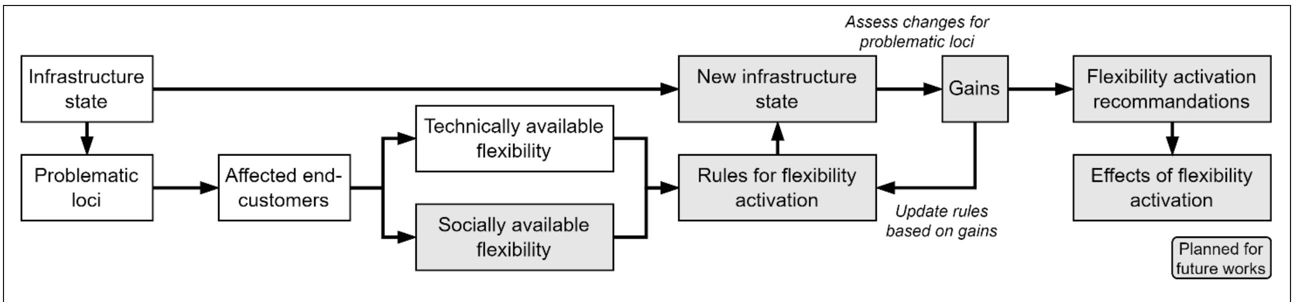

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Fig. 9 – General flow diagram for the proposed methodology

3.3 Methodology proposal for assigning and activating flexibility

With the identification of problematic loci by LV line peak load analysis and the partitioning of impacted end-customers, the first steps for the complete envisioned methodology are in place. Figure Fig. 9 displays the general flow diagram of the methodology. The remaining steps are discussed in detail in chapter 4.

With this methodology, the end result will provide the DSO with operation commands in the form of recommendations to apply at select end-customers' installations, leveraging their potential flexibility as a tool for reducing peak loads observed in the distribution grid and optimal operation and use of the existing infrastructure.

4. Future works

This chapter details the remaining planned works for completing the study "Flexibility shares in a low-voltage distribution grid". The steps described below will finalize the proposed methodology following already available results already discussed.

1) **Assigning flexibility**: When defining the available flexibility per end-customer, it is essential to determine whether the impacted end-customers accept a role of active contribution using their consumption and/or production profiles. To help with this step, results from Yilmaz et al. [10] will be leveraged to assign social acceptability ratings per end-customer that will be then use when defining flexibility activation rules.
2) **Defining flexibility activation rules**: The previous steps defined the list of affected end-customers with power loads available for flexibility activation and accepting of this activation. Next, the rules for implementing this activation based on availability and needs will be defined. Several approaches are currently considered, utilizing stochastic and greedy algorithmic implementations to list the end-customers to target with flexibility activation commands. After each command, the effects will then be evaluated to again influence activation rules based on the results in a feedback loop model aiming to find to optimal commands for flexibility activation.
3) **Assessing the effects of flexibility activation**: At the end of the process, an assessment of the gains and consequences of flexibility remains to be done. The analysis of these effects encompasses for example in-depth study of load impact on grid infrastructure using the resulting load curves in grid simulation software to compute voltage evolution, financial estimating of differed energy exchanges caused by load displacement, or impact for the end-customers and their consumption habits.

Conclusion

Working with AMI and GIS/NIS data, the results in this study have shown the possibilities for load analysis and load peaks identification in a low distribution grid. Furthermore, when integrating end-customers descriptions, their respective contribution to the peaks can be broken down in categories with installations with flexibility activation potential. Using these results, the times and places where the flexibility activation would serve the distribution infrastructure by reducing the load peaks are identified, in combination with end-customers to potentially target to this activation.

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In future works focusing on flexibility activation, the rules of activation and their effect on the infrastructure and end-customers will be studied with the objective to devise a complete methodology used by the DSO for optimal operation of the distribution grid.

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Evaluating the Market Attractiveness for Fuel Cell Micro-Cogeneration

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Overview

A market attractiveness analysis was conducted on the participation of residential fuel cell micro combined heat and power plants (FC- mCHPs) in the European grid service markets as part of the FCH-JU funded “Pathway to a Competitive European Fuel Cell micro-Cogeneration Market” (PACE) project. The aim of the analysis was to identify the most promising countries for FC-mCHP participation in grid services markets. As a number of factors of varying importance were considered in the selection process, a Multi-Criteria Evaluation (MCE) approach was applied to compare alternatives and formalise a decision. In the given context, the MCE method was used to rank alternative countries based on a set of evaluation criteria that define a country’s attractiveness. Criteria were identified and then weighted based on the conducted literature research and the results of the analytical hierarchical process applied during expert interviews with FC-mCHP manufacturers respectively. This resulted in a weighted definition of market attractiveness made up of factors relating to the economic value (comprising of spark spread, self-consumption policy and market potential) and market potential (comprising of potential market size, heat demand, future policy changes, and existing installed base). For each country an overall country score was then determined. The results of the MCE indicate that besides Germany, which was already proposed as a candidate by the PACE project, Belgium, the United Kingdom, Ireland and Italy currently have the highest market attractiveness for FC-mCHP’s in Europe. In a later stage, scores were further enhanced by considering potential grid services revenues, as well as the regulations relating to market access for domestic flexibility and a high-level consideration of potential grid services revenues.

Goals

- Identification of relevant criteria for the evaluation of the market attractiveness based on literature research
- Creation of a shortlist of four countries from the EU-28 countries, Norway and Switzerland by applying the process of multi-criteria evaluation (MCE)
- Validation of the results of the MCE based on a review with the PACE team and advisory board
- Identification of suitable grid services

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Scientific Approach

An MCE was conducted with experts to analyse the market attractiveness of a country. It is a structured approach to formalise a decision and to compare alternatives. In the given context, it was used to rank alternative countries based on a set of evaluation criteria defining their attractiveness (multi-attribute decision-making) [1]. The MCE was conducted following four steps:

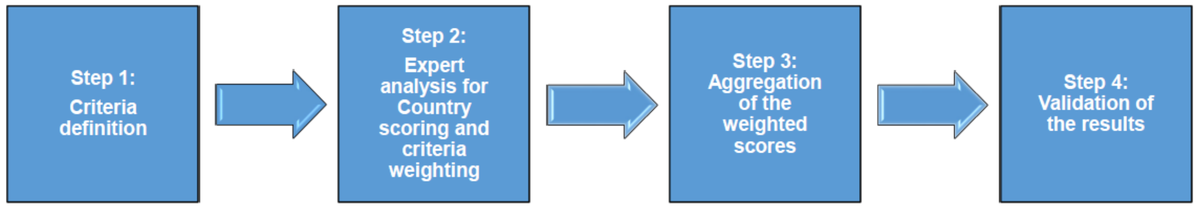

Figure 1: MCE Factor Tree including criteria weights.

Step 1: Criteria Definition

Analytical hierarchical process (AHP) is a method used for pairwise comparison of elements or criteria, which are structured in defined hierarchy resulting in weights for the criteria and checking the consistency of the evaluation [2]. Relevant criteria for the evaluation of the market attractiveness were identified and chosen based on literature research:

Spark Spread
The spark spread is defined as the economic value added from producing one unit of electricity, by considering the costs for the primary
fuel (natural gas) and the efficiency of the FC-mCHP. The larger the spark spread between the gas and electricity prices, the higher is the attractiveness of the technology [3].

Self-Consumption Policy
Favourable self-consumption policies improve the business case by using the electricity on site instead of feeding it back into the grid at a lower tariff. Attractive self-consumption policies improve the business case for fuel cell micro-cogeneration.

Governmental Subsidies
Government support programs, such as investment support, feed-in tariffs or tax incentives allow for a decrease in investment or
increase in revenue during the operation period, which leads to a higher EVA. As stated in [4] the cost of a fuel cell is much higher than traditional heating technologies and therefore requires support schemes to establish itself in the market.

Potential Market Size
An indicator for the potential market size is the market share of gas heating systems or the number of households which are connected to the gas grid. As stated in [5] future boiler market expectations are a good indicator for the potential market size for FC-mCHP.

Heat Demand
The characteristics of a typical building or climate conditions have an influence on the heat demand [6]. Those two factors have a significant influence on the annual load duration

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curve and hence the utilisation of the CHP unit. A higher heat demand is seen to lead to a higher attractiveness for FC-mCHP.

Future Policy Changes
Policies can have a significant impact on technology, especially one such as FC-mCHP that couples the electric and gas sector and is thus subject to both policy frameworks.

Installed base
This criterion considers the number of installations from previous and ongoing projects such as ene.field and PACE, as well as installations of conventional mCHPs. The installed base gives an indication of existing supply chains and the willingness for people to buy the technology.

Step 2: Expert analysis for Country scoring and criteria weighting

- One-on-one interviews with the manufacturers participating in PACE
- A balanced scale, ranging from “far below average” to “far above average” was applied to evaluate the country scoring with respect to each criterion, resulting in a numerical grading from 0 to 9. A 0 is assigned where no data is available, 1 is assigned when the grading is “far below average”, and 9 is applied where the grading is “far above average” [7].
- Relevance of each criterion was then assessed in a pairwise comparison, as shown in Table 1. In this instance, the criterion A (*EVA)* has been rated “more relevant” than criterion B (*Market Potential),* resulting in the intensity value 5.
- A weighting value is calculated considering an aggregation of each expert’s intensity value.

Table 1: Comparison of relevance example for EVA and Market Potential criteria based on [8]

Criteria A	A dominates	A much more relevant	A more relevant	A slightly more relevant	A and B equally relevant	B slightly more relevant	B more relevant	B much more relevant	B dominates	Criteria B
EVA			X							Market potential
Intensity value	9 (Extreme importance)	7 (Very strong importance)	5 (Strong Importance)	3 (Moderate importance)	1 (Equal importance)	3 (Moderate importance)	5 (Strong Importance)	7 (Very strong importance)	9 (Extreme importance)	Intensity value

A consistency ratio (CR) was used to check how aligned the respondents’ answers were, where the linear fit method of calculating consistency as proposed by [9] was applied (see Equation 1).

$$CR = \frac{\lambda_{max} - n}{2.7699 * n - 4.3513 - n} < 0.1 \qquad (1)$$

λ_{max} = Consistency index
n = Number of criteria

The CR measures how consistent the judgments have been relative to large samples of purely random judgments. If the CR is in excess of 0.1, the judgments are untrustworthy because they are deemed too random [10].

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Step 3: Aggregation of the weighted scores

For each country, the scores for the criteria were multiplied by the criteria weighting and summed up, resulting in an overall country score (see equation 2). Based on this score a raking of the countries could be created.

$$Country\ score = \sum w_i * x_i \qquad \begin{array}{ll} w_i & = \text{Weighting factors} \\ x_i & = \text{Criteria scores for country} \end{array} \tag{2}$$

Step 4: Validation of the results

The *criteria* weighting and the selection of countries were both reviewed and accepted by the PACE team and advisory board.

Results

Figure 2 illustrates the aggregated weights of each criterion according to the manufacturers in a factor tree.

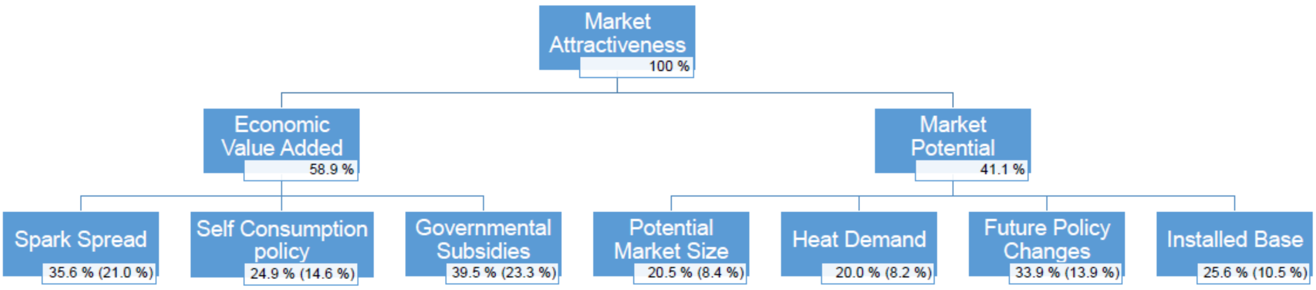

Figure 2: MCE Factor Tree including criteria weights.

From this, the following can be understood:

The current *economic value added* that the technology yields has more relevance or holds more weight when compared to *future market potential*
The existence of *governmental subsidies* is the single factor of greatest concern to the manufacturers when looking to enter a market, followed closely by the *spark spread*
Potential market size, heat demand and *installed base* are seen to play a minor role in comparison to other factors.

Based on these weights, the final scores for the countries were evaluated resulting in Belgium, Italy, Ireland and the United Kingdom as the top four countries, followed by the Czech Republic, the Netherlands, France and Spain. Figure 3 illustrates the individual scores for each criterion as well as the final overall score for each of the four countries based on the manufacturers' market knowledge. It is important to note is that it was made explicit by the manufacturers that their knowledge of European markets is limited to Central and Western Europe. As such, countries outside these regions were discarded. This reduced the number of countries considered for the MCE by approximately half.

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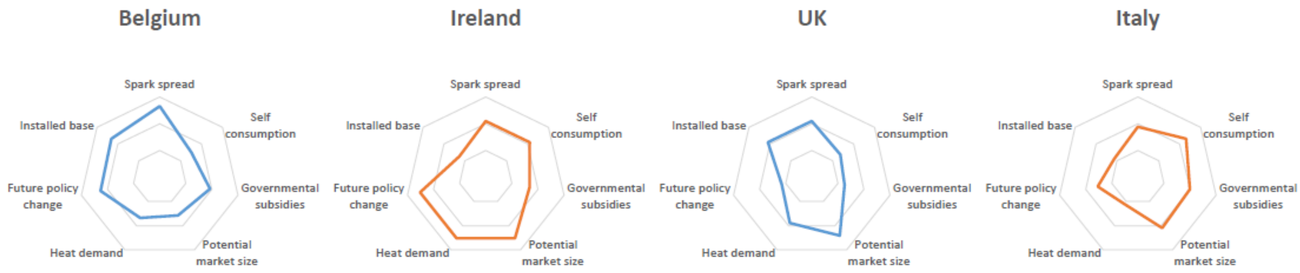

Figure 3: Spider diagrams of final four selected countries based on the MCE

For the grid service market evaluation, Czech Republic was added at the request of the pace consortium due to its underlying energy mix, which contrasted the other shortlisted countries. Suitable grid service market products were identified based on the following, and are summarised in Table 2:

- Existence of grid service market products suitable for FC-mCHP
- Ease of market accessibility
- Market designed remuneration (capacity market or energy only market)
- Information quality and availability of data

Table 2: Technical requirements of grid service descriptions and the suitability for mCHP

Service and country	Minimum bid size	Notification time	Prequalification	Product resolution (min. bid length)	Symmetrical
mFRR Belgium	1MW ●	15 min ●	*Pooled level ●	15 min ●	No ●
aFRR Czech Republic	3MW ◍	10 min ●	Pooled level ●	1 hour ●	Yes ○
mFRR Czech Republic	10 MW ○	5-15 min ●	Pooled level ●	1 hour ●	No ●
aFRR UK	25 MW ○	2 min ○	Pooled level ●	Month ○	No ●
mFRR UK	3 MW ◍	4 hours ●	Pooled level ●	Week ◍	N/A

● Suitable for mCHP ○ An improvement could significantly increase mCHP participation ◍ An improvement could increase mCHP participation

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Grid Services as Byproducts of Water Electrolyser

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Abstract

The article highlights the value of provision of flexibility services to the electricity industry. Generation as well as load and storage technologies can become reserve providing units. Relevance of the flexibility business as well as opportunities and challenges offered are discussed, mostly from a perspective of distributed, small- to medium-sized units. An example is given where frequency balancing offers an important contribution to the cost reduction of hydrogen. However, it is also shown that apart from frequency balancing, markets are not yet well developed.

Introduction

Forced electrification and a change from fossil-based energy generation to CO2-free generation with a relevant share of variable renewables poses major challenges for the power grid at all levels. If net CO2 emissions are to be reduced to zero by 2050, the share of renewables must more than double from 1.45 Gtoe worldwide to 3.37 Gtoe by 2030 ([4], p. 27 and **Figure 1**) In this way, an easily storable energy source is replaced on a large scale by a variable one that is difficult to predict. However, since the electrical grid cannot store significant amounts of energy, flexibility solutions are necessary.

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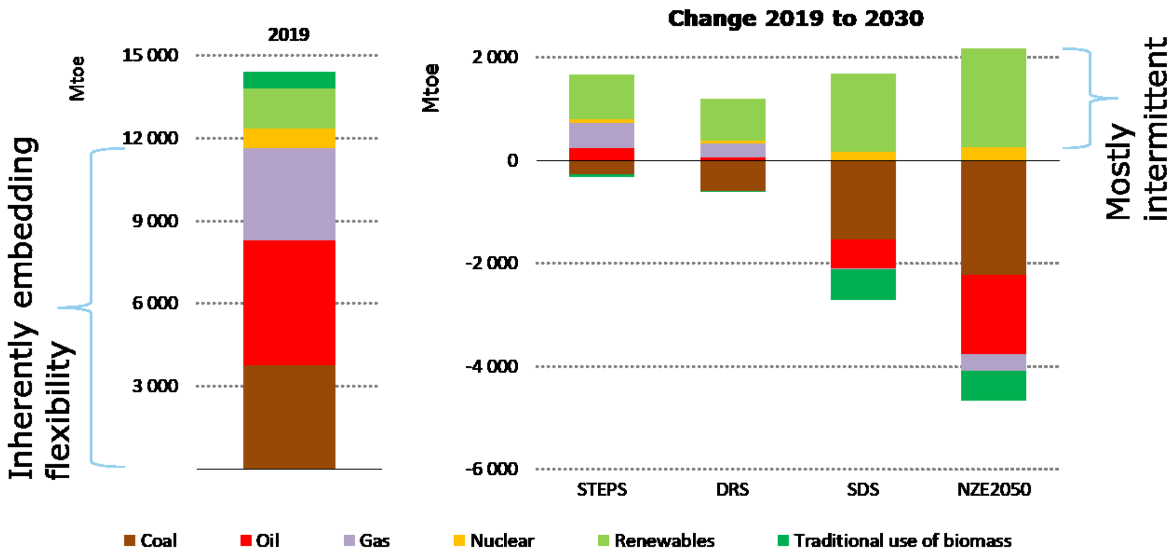

Figure 1: Variable renewable energy sources replacing fossil. Based on [4]

USEF defines flexibility as the ability to purposely deviate from a planned / normal generation or consumption pattern. This ability can be deployed either directly, by an external signal, or indirectly as a response to a financial incentive such as energy prices and tariffs. (USEF, 2018, pp. 4f) Flexibility is a value that is partly already traded now. This presentation deals with flexibility, the value of its provision and possible future developments of flexibility markets.

The vulnerable electricity grid needs flexibility

The electricity grid connects power generators with loads. Large (national and international) distances are bridged by the high voltage transmission grid (e.g. 110 kV, 220 kV, 380 kV) and regional distances are bridged with medium (e.g. 10 kV, 20 kV, 30 kV) and low voltage (e.g. 0.4 kV) distribution grids. The traditional electricity grid is built such that generation follows consumption, where generation can be planned, and the energy flow is roughly from the transmission grid via the distribution grid to the loads. With the transition towards a sustainable energy system the characteristics of generation change drastically: renewable energy generation such as PV and wind, which are distributed and variable may turn the flow of energy in the distribution grid, and generation does not naturally follow a plan. In addition, electrification of mobility and heat / warm water sectors increase loads. Thus, a series of challenges arise.
On the national and international level, adequacy is one of the major concerns. Generation capacity and consumption may mismatch in time and space. High PV production in summer cannot easily be made available in winter (**Figure 2**), and high wind generated power from the north cannot easily be transmitted to the south of Europe. In the short term, generation and load may be unbalanced, leading to deviations of the grid frequency. Furthermore, inefficient use of valuable assets can result in high variations in power flows.

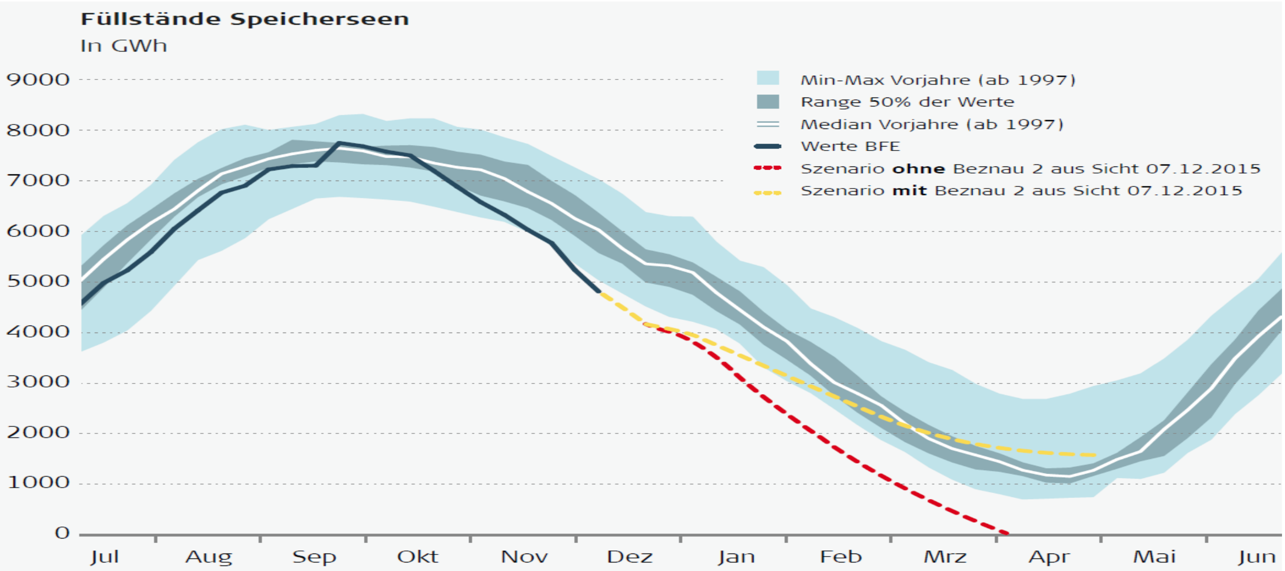

Figure 2: Example of an adequacy issue in Switzerland, 2015. The blue area of the figure shows the cumulated fill levels of Swiss storage lakes between 1997 and 2015. In winter 2014 / 2015 several French nuclear power plants were taken off the market, with the result that the Swiss storage lakes were at a historically low level on 7 Dec 2015. The dotted yellow line represents the expected situation with an active nuclear power plant Beznau 2, and the dotted red line represents the expected situation without Beznau 2, pointing to serious problems towards the end of spring (Swissgrid, 2016).

On the regional and local level, grid congestion, power peaks and voltage deviations may arise. The distribution grid has to absorb large amounts of renewable electricity from a number of decentralized power plants (mainly PV and wind) with irregular power production and high peaks. The supply of electric vehicles additionally leads to power peaks at times that differ from production peaks (**Figure 4**). Forced installation of heat pumps at the same time increases loads, but also offers new flexibility options (**Figure 3**).

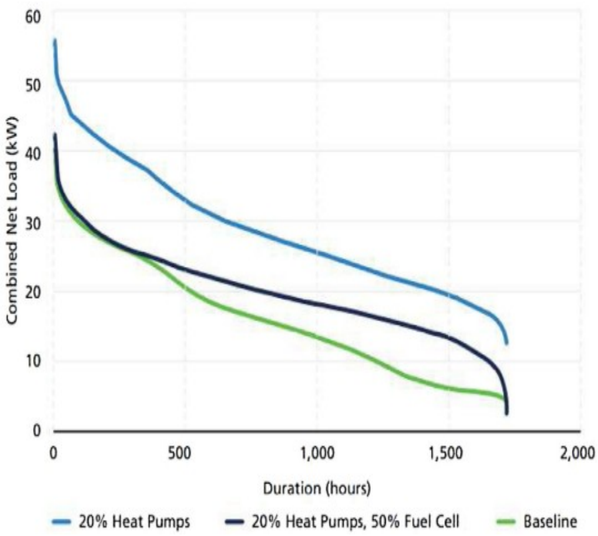

Figure 3: Load duration curves for homes heated using: (i) natural gas (baseline); (ii) 20% of gas boilers replaced by heat pumps; and, (iii) 20% heat pumps and 50% micro-CHP fuel cells. Data are based on measurements from 46 dwellings [2].

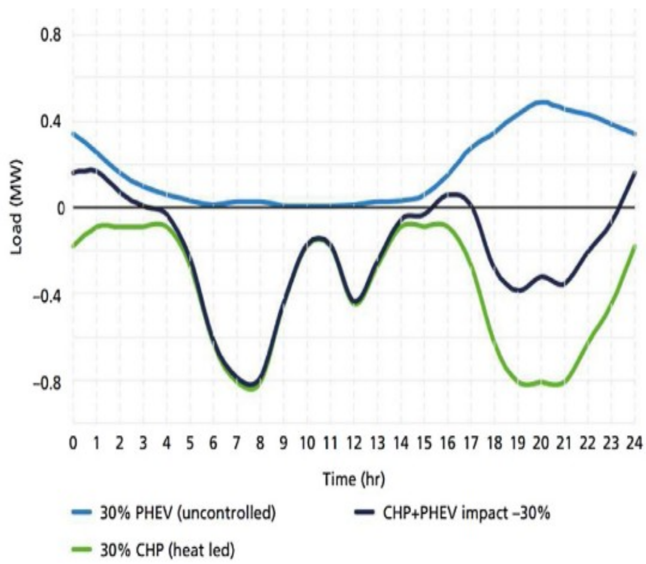

Figure 4: Fuel cells can compensate for the evening load increase from plug-in hybrid electric vehicles on distribution networks [2].

In their Net Zero Emission 2050 scenario, the International Energy Agency IEA expects a 52% share of electric vehicles by 2030. Average annual capacity addition of wind and PV in the years 2020-2030 is 4.5 times the average of the last decade. (**Figure 5**)

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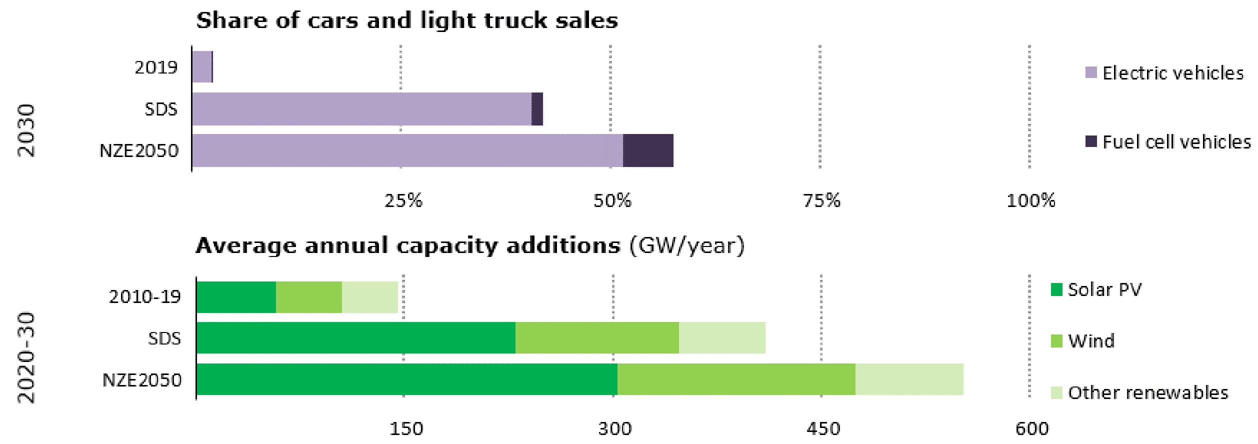

Figure 5: Deployment of sustainable technologies under the Sustainable Development Scenario (SDS) and the Net Zero Emission 2050 Scenario (NZE2050) till 2030. (IEA 2020, p. 54)

Roughly 60% of the European electricity generation is made up of dispatchable conventional power plants. It is likely that these will continue to satisfy the majority of the flexibility demand (Klemenz et al., 2019, p. 21). However, there is room for additional flexibility solutions, as can be seen already today with flexibility markets opening for aggregation of medium and small sized reserve providing units (**Figure 6**), capacity markets and operating reserve prices.

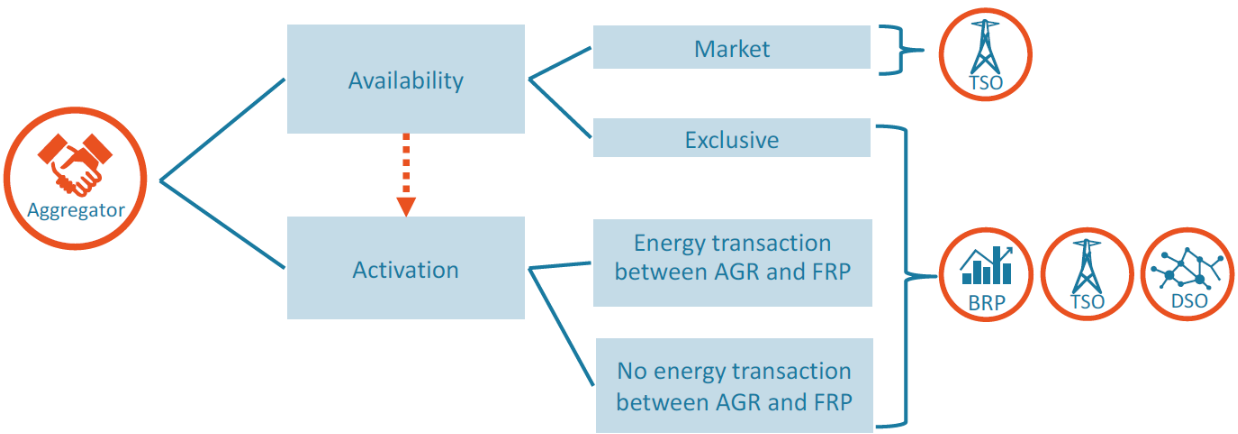

Figure 6: Aggregators build virtual power plants (VPP) by combining a multitude of small and medium sized reserve providing units, offering flexibility (availability and activation) to transmission system operators (TSOs), distribution system operators (DSO), and possibly balance responsible parties (BRPs). FRP: flexibility requesting party; AGR: Aggregator (USEF, 2018, p. 14)

Summarizing, the intelligent use of existing and introduction of new sources of flexibility is needed to a large extent. On the local level, the advancement of e-vehicle markets and variable renewables increase pressure on grid capacities and thus open up market opportunities for decentral flexibility solutions. On the national and international level, an increasing demand for flexibility in the next decades is expected. Thus, an increase of the need for 'flexibility' as a whole can be expected for the next three decades. Forecasts on the development of single flexibility products, however, is difficult to achieve, since the way in which flexibility is rewarded is politically driven (Klemenz et al., 2019, p. 21).

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The promise of flexibility and its cost

Though typically not the only business, provision of flexibility can lead to a relevant additional income for the operator of a reserve providing unit. **Figure 7** shows the impact of different frequency balancing products (automated and manual frequency restoration response (aFRR and mFRR) and frequency containment response (FCR)) on the levelized cost of hydrogen (LCOH) for 1 MW water electrolyzers in the German and Norwegian frequency-balancing markets. In the case of Germany, the impact of the ‘Erneuerbare Energien-Gesetz’ EEG is neglected. Depending on the annual full load hours and balancing product, a considerable additional income– expressed as reduction of hydrogen production cost – can be achieved. It must be noted that in real cases the income from the frequency-balancing markets would need to be split between the operator of the reserve providing unit and the aggregator managing the flexibility of the unit.

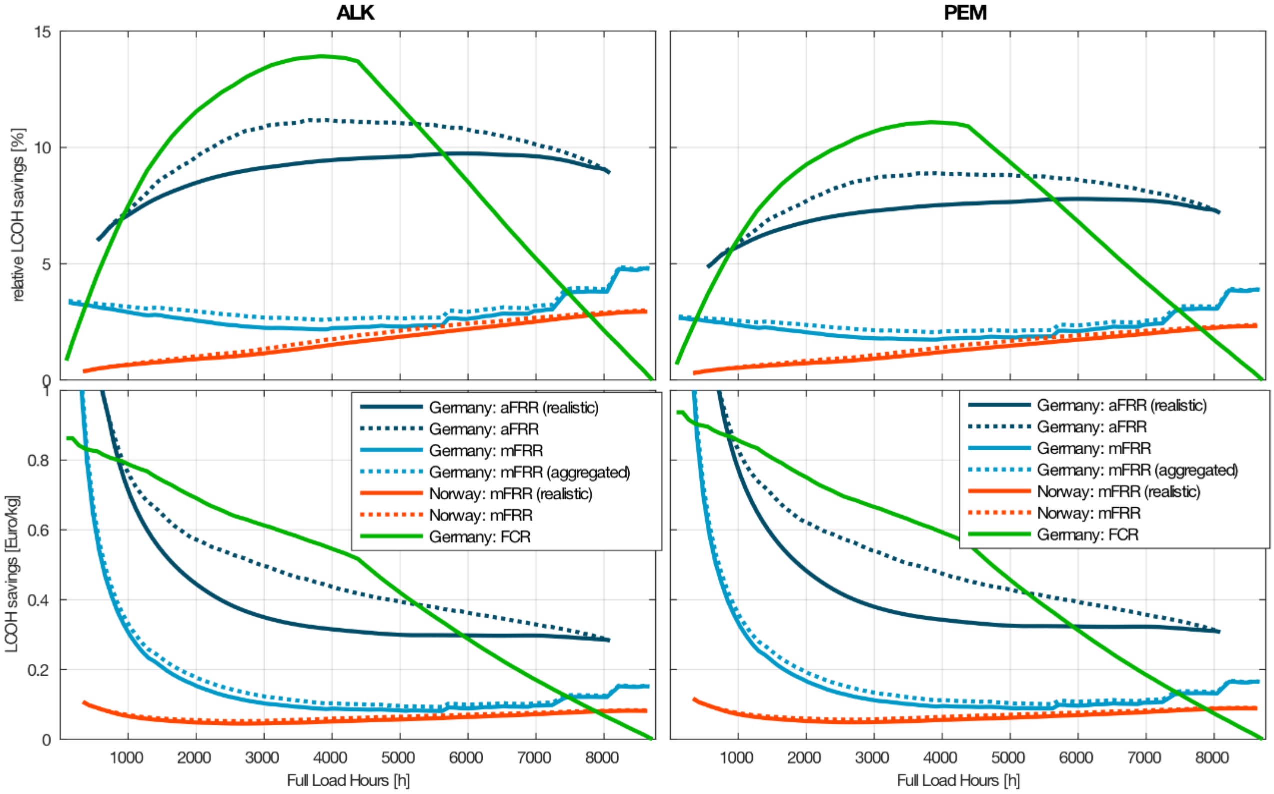

Figure 7 Participation of a 1 MW water electrolyser gives an additional income, reflected as a reduction of the hydrogen production cost (LCOH). Left: alkaline and right: PEM water electrolyser. Based on prices from 2016. (Klemenz et al., 2019, p. 66)

In many European countries, liquid markets exist for frequency-balancing products, with similar characteristics due to harmonization efforts of Entso-E. Mechanisms such as the aggregator model open market access for medium sized and smaller reserve providing units (**Figure 6**). Aggregators collect multiple units as a single virtual power plant (VPP), simplifying demanding requirements for individual reserve providing units such as minimum nominal power of the unit, reaction time, activation duration, availability, prequalification or administration. Depending on national regulations, aggregators have a more or less liberal access to the market, or may not even exist (**Figure 8**).

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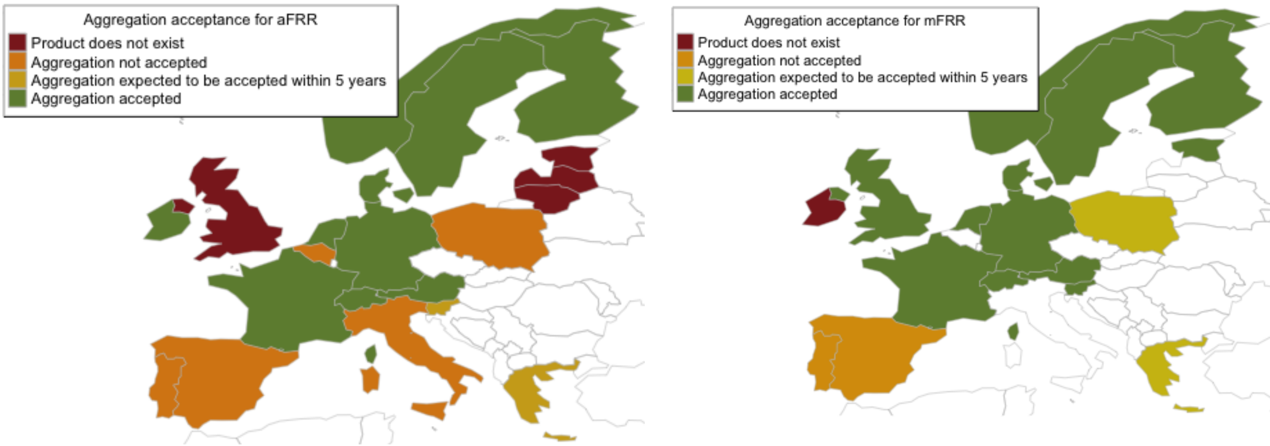

Figure 8: Aggregation acceptance for automated and manual frequency restoration response (aFRR, mFRR), base 2016 [7]

On the local and regional side, however, market places for congestion management, peak shaving or voltage control are not yet established, though there are ongoing pilot projects such as the German integrated market project enera [8]. Here the flexibility business typically bases on bilateral agreements.

For small-sized units, control and monitoring requirements – if not based on pre-existing infrastructure – often are a very high hurdle. Power monitoring with a resolution of two seconds may be required. In addition, remote control is a prerequisite for many aggregators – even if a transmission system operator (TSO) doesn't require it in the case of mFRR.

In many places, price levels for frequency balancing have decreased in the last decade (Figure 9). Though the long-term perspective is optimistic with growing demand, the current price level may disincentivise market entrance especially for sustainable technologies.

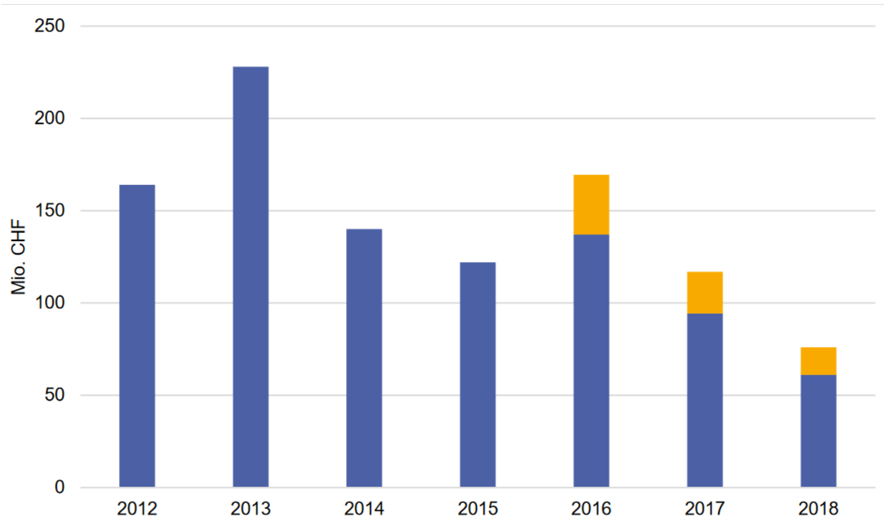

Figure 9: Procurement costs for balancing power by the Swiss TSO (Swissgrid), including availability of FCR, mFRR, aFRR, RR. Blue: regular procurement; yellow: early procurement. [9, p. 8]

Reserve providing units may need updates in order to fulfill prequalification requirements. E.g. the control system of water electrolysers must be changed from hydrogen output control to electrical input power control. As long as updates can be implemented as software updates, and are foreseen by the manufacturer, these costs can be neglected. However, in cases such as voltage control, where the power converter must be extended, the costs are most probably prohibitive.

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Frequency balancing markets are expected to become internationalized as demonstrated in ongoing pilot projects such as MARI [10] and PICASSO [11]. It is expected that internationalization of frequency balancing markets will level out national price differences.

Summary – Conclusion

Frequency balancing markets are well developed in most European countries nowadays, offering the possibility for additional income, where flexibility such as unused capacity of a reserve providing unit can be offered. Typically, this is done via an aggregator. Other flexibility services such as congestion management or voltage control, are not yet established, though pilot projects as well as bilateral agreements between reserve providing units and e.g. distribution system operators (DSOs) exist.
In the long term, the demand for flexibility is anticipated to increase, triggered by variable renewable energy sources, closure of fossil fuel power stations and ongoing electrification. However, the arrangement of single flexibility products has strong political influence. Thus, little can be known about the future evolution of specific flexibility products.

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G06
Future of Grid Service Markets

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G0602

Introduction of the "Syste(M)arket"
A Systemic View on Market and Grid

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Abstract

The European energy transition is accompanied by a fundamental transformation of our energy demand and supply structure. This also has significant impact on the future demand and provision of ancillary services, which are necessary for a robust system operation. Thus, it becomes essential that the future market design is able to support this transformation based on a systemic approach considering the energy system as a whole. In today's electricity market design, the needs for a secure operation of the transmission grid (e.g. grid expansion, ancillary services, etc.) are often not adequately taken into account in the investment and operating decisions of market participants. This issue is addressed by the "Syste(M)arket" concept, which aims for ensuring sufficient potential to guarantee generation adequacy and system security. It is an integrated and at the same time modular market design that considers all the necessary needs of the energy system. In this respect, it represents an important supplement to the existing spot and forward markets and thus ensures the long-term provision of these needs. It sets incentives to ensure that sufficient flexibility and required ancillary services are available at the right places from a systemic point of view and that plants are properly designed to leverage synergies.

Keywords: Syste(M)arket, market design, local energy markets, local capacity markets, ancillary services

Introduction

Germany has committed itself to the objective of becoming climate neutral by 2045. This requires the fundamental transition of today's energy supply to a highly efficient and sustainable energy system based on renewable energies. Consequently, conventional power generation is rapidly being phased out and new environmentally friendly power plants are required to ensure a secure power supply as well as to provide flexibility, already in the next few years. The same applies to necessary ancillary services, which today are mainly provided by conventional power plants, often even inherently and free of charge. In the future, the increasing local demand for these ancillary services will have to be covered as well, but for example by renewable energies, flexible consumers or storage facilities. The in the following presented "Syste(M)arket" concept provides a framework for

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an integrated demand assessment, the market-based procurement, and the long-term provision of ancillary services.

1. Requirements for Grid Services - Technical & Market Conditions

The expansion of renewable energies in Europe has a massive impact on the generation structure and, consequently, on grid operation [1]. Especially, the changing demand and provision of essential ancillary services (e.g. for frequency or voltage control) represents an increasing challenge for transmission system operators (TSOs). Currently, in most countries there are just insufficient incentives for market participants to provide additional ancillary services. However, new markets and concepts for their future-proof provision are under development and being assessed in various countries [2,3]. For the case of Germany, Schlecht et al. [4] evaluates the current demand, potential provision, and the need for additional procurement of ancillary services. Based on their assessment, there are currently individual concepts for the market-based procurement of the ancillary services black start capability and reactive power supply in development. One important aspect of the demand assessment for ancillary services is the selected criterion for dimensioning the demand (e.g. normal operation, in the event of an error/failure, in the event of a required power system restoration, etc.). For example, in the case of inertia as an ancillary service, the assessment shows that there is no additional demand in the short term. However, this result is based on the assumption of a dimensioning error of the primary control due to a power imbalance of 3 GW. Further analyses within the German Grid Development Plan (NEP) [5] show that in the event of a system split, significantly higher power imbalances occur and, at the same time, less inertia is available due to the shutdown of conventional power plants (cf. Fig. 1).

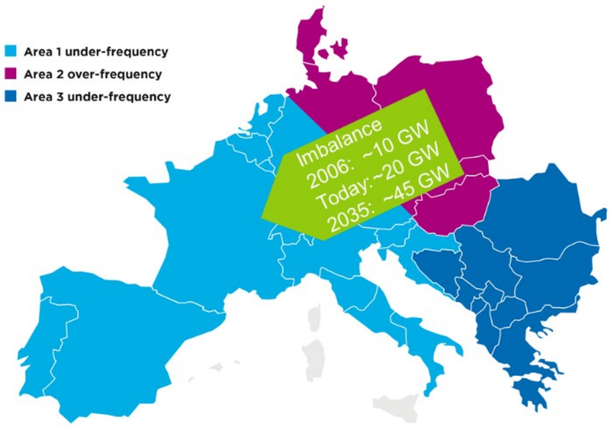

Fig. 1: Potential development of power imbalances in the event of a system split (e.g. on 4th Nov 2006)

2. Introduction of new Approach for Future Grid Service Markets

The “Syste(M)arket” represents an integrated and at the same time modular market design concept which provides solutions for the described challenges in a way that it represents a necessary supplement to the existing spot and futures markets and thus ensures the long-term provision of essential needs of the energy system (cf. Fig. 2). This is accomplished by the initiation of spatially and objectively differentiated payments in order to create economic incentives for system-serving investment decisions of market participants. In

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other words: the concept of the Syste(M)arket aims to take a systemic view on market and grid instead of considering both as being rather stand-alone systems. Instead of handling only the ‘small’ overlapping part of both, the Syste(M)arket considers market and grid to be addressed in the context of the overall energy system.

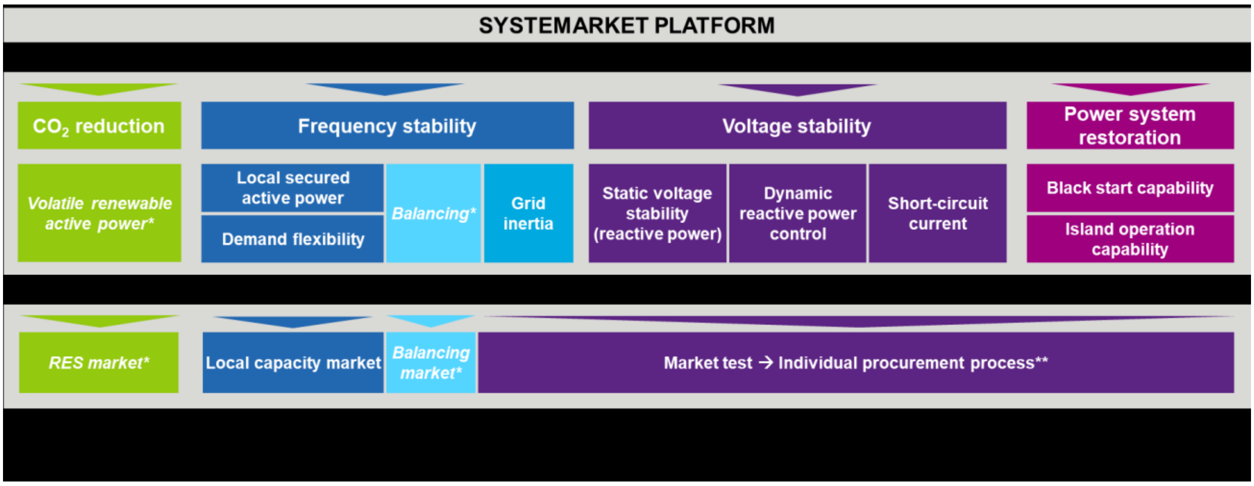

Fig. 2: overview of the Syste(M)arket of central platform for the system needs

Its basic approach works similar to a central capacity market, but with a higher spatial granularity and enhanced by the consideration and implementation of ancillary services. In a first step, the overall system needs to ensure generation and transmission adequacy as well as secure grid operation (e.g. local reactive power demand, grid inertia, etc.) are determined. Within this process, every system need is represented by an individual module of the Syste(M)arket. The diversity of the individual system needs and especially of ancillary services requires individually tailored procurement procedures. "One-fits-all” solutions for all system needs are therefore not efficient. For that reason, the most effective and efficient procurement process for each module of the Syste(M)arket is determined and implemented (cf. Fig. 3).

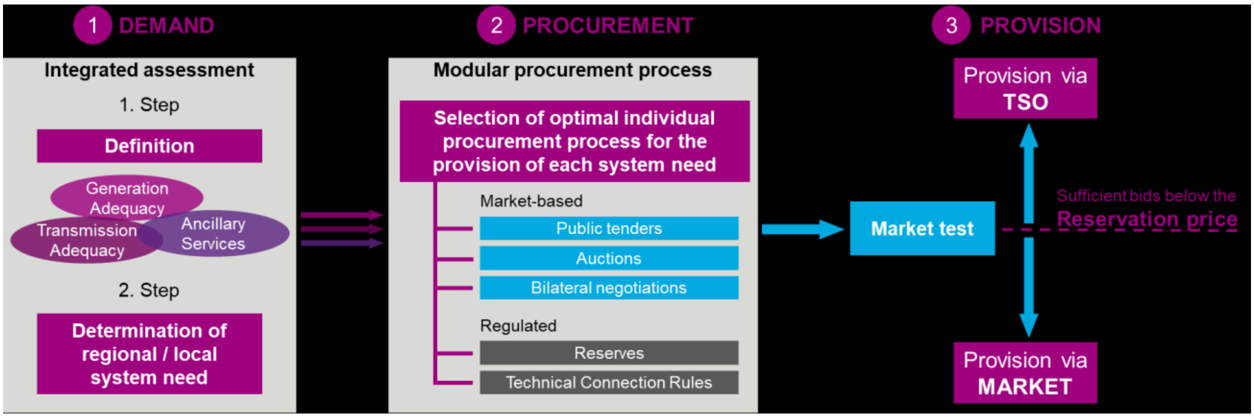

Fig. 3: schematic diagram of the Syste(M)arket concept

There is a wide range of potential procurement processes considered in the concept (e.g. public tenders, auctions, etc.). The selection of procurement process is based on several criteria, like the standardizability of the products, the homogeneity of the market, technology and cost environment, and the expected local market liquidity.

The procurement procedures are also regularly reviewed and reassessed to ensure that the best procedure from a technical and economic point of view is also used for the

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respective procurement period. Particularly in the event of a change in the demand situation or the market penetration of new technologies, an adjustment of the procedure may be necessary. In addition, it is possible that different procurement processes are run simultaneously, e.g. due to different technologies available for its provision.

There are basically three options for covering the expected demand: the definition of technical capabilities of plants via Technical Connection Rules (TCR), market-based procurement, and the provision by the transmission system operator (TSO). Identified needs are to be procured through TCR if it can be properly demonstrated that appropriate specifications to ensure secure system operation must be met by each market participant. However, if locally there are higher demands, it could become necessary to meet the (additional) demand through market-based procurement processes that exceeds the requirements of the TCR or through the provision by the TSO (cf. Fig. 4).

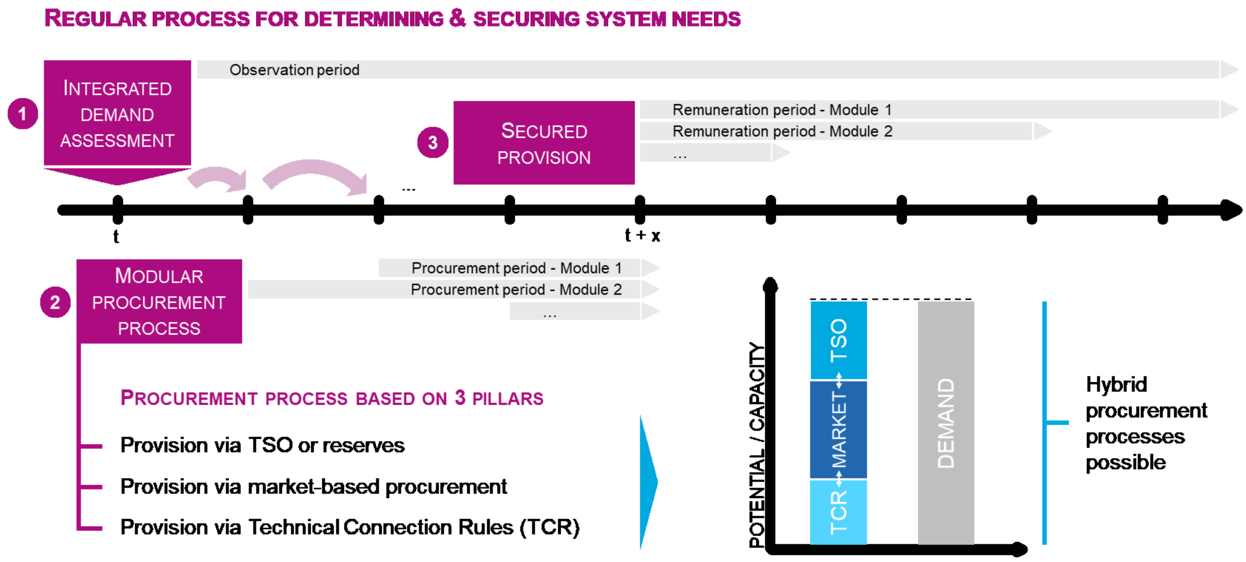

Fig. 4: schematic diagram of the overall process and different periods in securing the system needs

The above-mentioned options can also be combined. For example, local or temporary requirements beyond the minimum requirements defined by the TCR can be tendered. Similarly, some ancillary services could be broken down into more detailed technical characteristics, and if necessary, procured or remunerated individually. An example of this would be the differentiation of reactive power according to slow or fast activation, e.g. after the occurrence of an outage situation.

Overall, this multi-stage process ensures that the market participants receive incentives for system-serving design and site selection and, at the same time, market-based procurement is limited to those system needs that can be efficiently provided by market participants.

3. Conclusion

The Syste(M)arket concept is a necessary supplement to the existing spot and forward markets, which aims for ensuring the long-term provision of the necessary needs of the energy system. It is based on a systemic view on the energy system, implementing a regular process for an integrated demand assessment and modular procurement of ancillary services and other system needs. The major benefits of this market design are:

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(1) it is providing a systemic view on the dimensions of security of supply (generation adequacy, transmission adequacy, ancillary services); (2) it is implementing a necessary integrated demand assessment process; (3) it is providing incentives for system-serving behavior of market participants; and (4) it is cost efficient due to market-based procurement processes. Potential drawbacks of this design are: (1) it is based on a comparatively complex process; and (2) the system efficiency is dependent on the efficiency of the central planning process. All in all, the Syste(M)arket ensures that sufficient capacities for the provision of each system need are available at the respective locations in order to guarantee the secure operation of the overall electricity system at each time in the future. In case of Germany in a first step, the Syste(M)arket could include for example the implementation of a local capacity market in combination with modules for the procurement of reactive power, black start capability and inertia.

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G0603

Effects of variable grid fees on distribution grids with optimized bidirectional battery electric vehicles

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Introduction

The ongoing electrification of the mobility and heating sector, which is a good possibility to reduce greenhouse gas emissions, leads to new flexible components in the energy system [1]. Especially, electric vehicles (EVs) with relatively high charging powers and large battery capacities can help to integrate renewables into the system [2]. Therefore, the EVs, with their high parking time of more than 23 hours per day [3], can be used as a storage if they are not only charged but also discharged, which is called bidirectional charging. Often the integration into the grid or energy system is also referred to as vehicle-to-grid (V2G) [4]. With bidirectional charging many different use cases, e.g., PV optimization, trading as well as grid services are possible [5]. The different use cases in addition to electrification also place new demands at the electricity grids, especially the low voltage grid, where most of the EVs are connected via charging stations at home or work [6].

To motivate customers to use or provide the flexibility of their EVs, this must be financially or at least environmentally profitable for them, if not mandatory. One possibility is to charge the own PV energy, whose production costs are below the price of electricity consumed from the grid. The electricity price in Germany can be divided generally in three main parts. First the procurement price, which reflects the producers' generation costs and is around 26 %. Secondly, the grid fees, which are incurred for the use of the public electricity grids and depend on both the grid level and the grid operator. On average the grid fees in the low voltage grid were 7.17 ct/kWh respectively 22 %. Thirdly, the taxes, levies and surcharges that are added represent 52 % [7]. Beside the procurement costs, the grid fees are one of the main cost components, and therefore analysed more in detail in this paper.

The grid fees today for typical consumers like private households are charged per kilowatt hour regardless of the current grid load. Thus, there is currently no incentive for customers to behave in a grid-serving manner. In the future, variable grid fees could help with the integration of new consumers as well as renewable energies. Different options for variable grid fees are discussed in literature [8], which can be summed up in three categories: time-based variable, congestion-oriented or dynamic fees linked to the electricity price. The following methodology focuses on congestion-oriented variable grid fees.

Keywords: bidirectional charging, electric vehicle, grid integration, distribution grid, flexibility, energy system analysis, variable grid fees

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Methodology

The grid impacts of cost optimised EVs and storage units with variable grid fees were analysed using the distribution grid and energy system model GridSim. The model developed at FfE enables detailed simulations of low and medium voltage grids based on a load flow calculation [9], [10], [11]. An overview of the methodology combining the required input like low voltage grids, future scenarios, parameters, and use cases, the different function used inside the GridSim model as well as the output is shown in Figure 10Figure 10.
The analysis was carried out for 1206 real low-voltage **grids** from Bavaria (Germany) prepared in an upstream process representing a wide range of different characteristics e.g., to transformer size, line lengths and grid connection points (GCP). Additionally, today's load data was linked on a building level (same as GCP) including measured consumption for households, commercials and power-to-heat systems (PtH), like heat pumps (HP) and electric storage heaters (ESH), as well as with the known installed capacity of PV systems (PV). For customers with recording power metering, measured load profiles were used. [12]

To analyse the future grid load, regionalised **scenarios** for EV, PtH, PV and stationary battery storage (SBS) for the year 2040, which are based on today's grid allocation and had been developed according to the methodology published in [12], were used. Based on this scenario on average a building has 1.1 EV, 0.45 HP, 0.24 PV and 0.1 SBS within the analysed grids.

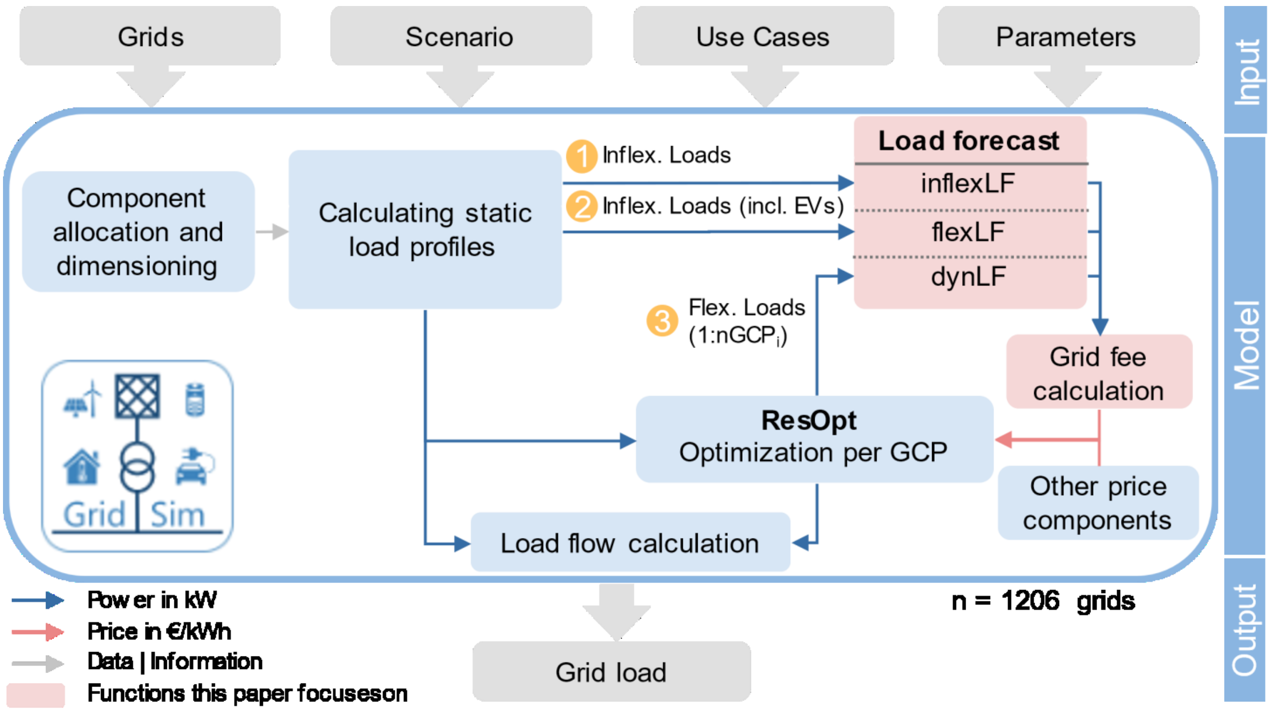

Figure 10 – Overview of the simulation model and the extensions for variable grid fees (red)

Based on energy system analysis and in discussions with experts, a mixed scenario regarding the usage of smart and bidirectional charging and the share of different use cases the following scenario was developed. 30 % of the GCP participate in **use cases** with bidirectional EVs and are therefore assumed to be flexible. At 17 % of the GCP (19 % of EV), a PV system and EV or SBS are present and self-consumption is increased (V2H).

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For V2H, consumers pay a fix price for electricity (24.38 ct/kWh) including the typical levies and taxes but without a fix grid fee of 5.05 ct/kWh and receive the EEG remuneration for electricity fed back into the grid (8 ct/kWh). The prices refer to the German electricity price design. The EVs and SBSs at the other 13 % of the GCP (17 % of EV) are given the opportunity for arbitrage transactions based on variable spot market prices for 2040 (described in [13]), so the EVs and SBSs can be charged and discharged back into the grid (V2G). In the case of V2G the EVs are considered like stationary grid storages in terms of taxes and levies (2.1 ct/kWh), which was described further in [14]. In addition, the grid fees are also compensated when feeding back electricity to incentivise grid-serving discharging in the V2G case. Just the 13 % GCP participating in V2G are subject to variable grid fees. Consumers of all other GCP behave in a demand-led manner or participate in V2H.

General **parameters** as well as parameters for dimensioning the components such as power and battery capacities are as documented in [14]. The most important parameters of the EVs are the charging and discharging power of 11 kW with charge and discharge efficiencies of 94 % (for 2040) and a battery capacity, which ranges from 38 kWh (26.6 % of the EV) to 60 kWh (40.6 %) and up to 100 kWh (31.8 %) due to different car classes [15]. Further on a simulation in 15-minute time steps for the weather and structure year 2012 was parameterised.

After defining grids, scenario, use cases and parameters a simulation is caried out for each grid, beginning with the **allocation and dimensioning of the components** and **calculating static load** profiles in the next step for households, commercials, EV, PtH and PV. In this case, SBS are only charged by the PV surplus. The methods these load profiles base on are described in detail in [14]. Additionally, further changes have been made to reproduce a more realistic electrical behaviour for EVs and PV systems.

Firstly, a state of charge (SOC) dependent plug-in probability model for EVs at home like described in [16] was implemented. In [17], the model has been extended to include a next trip consideration to ensure that mobility needs can be met. This module is only used for the demand-led charging strategies and therefore, the expectation value is set to 50 % in a normal distribution, with a standard deviation of 0.1 what leads to a realistic plug-in behaviour at SOCs around 50 % or lower. Furthermore, in the future scenario, all EV wallboxes and inverters of PV systems perform a voltage-dependent reactive power control (Q(V)) based on a defined characteristic curve. According to the technical connection specifications of the DIN VDE AR-N-4105 [18], grid operators can already demand Q(V) for newly installed PV inverters in low-voltage grids. For the simulation of the year 2040, it was assumed that Q(V) regulation will be standard for all PV and wallbox inverters.

The calculated static load profiles (Inflex. loads) based on a demand-led consumption pattern serve as input for the optimisation model ResOpt, secondly for the load flow calculation for GCPs without flexibilities and thirdly for the load forecast as well as the following grid fee calculation.

The cost optimisation is implemented within the **optimisation model ResOpt** as part of GridSim and used to determine the load profiles of flexible consumers like EVs and SBS by a linear optimisation at building level (GCP) [10], [11]. Therefore, three main price components are considered. Firstly, the price for the energy, which can either be fix or variable over time. Secondly, fees, levies and surcharges, which are added to the price, and thirdly, the grid fee, which is the focus of this paper.

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To analyse the effects of load- congestion-oriented grid fees two modules were developed and integrated in the simulation model. One to predict the grid load (**Load forecast**) and a second to calculate the variable grid fee (**Grid fee calculation**). The **load forecast** module allows three different methods with increasing complexity to forecast the transformer load. The first method (inflexLF) is oriented on today's possibilities of grid operators to predict the transformer load based on historic measurements. Therefore, the residual load consisting of inflexible profiles as households, commercials, PtH and PV is calculated. The flexible components, like EVs are neglected in this case since they are not known yet. In the second method (flexLF) the EVs are also considered. Therefore, the load profiles for all EVs are calculated in a demand-led manner, assuming that grid fees were constant and no other use case is performed by the EVs. So, if only some EVs are reacting to the variable grid fees or the fees are only seldom differing from the fix ones, this should be a good solution since the predicted load then does not deviate far from the actual load. The third method (dynLF) predicts the current grid load more precisely since the forecast considers the optimised GCP with flexible EVs and SBS one after another. Therefore, first all GCP loads without flexibilities and with fixed fees are calculated for the load forecast. Based on the load forecast the grid fees are calculated and after that the first GCP with flexible EV or SBS is optimized. This process is then done for every remaining GCP with flexibilities. So, in this case the forecast for the last GCP is almost perfect since all other load profiles are known. This method could be described as a reservation system, with live pricing and after a GCP was optimized respectively made his reservation the prices for all others are calculated based on this information. Finally, within this method different GCP have different grid fees.

The **calculation of the grid fees** is based on the forecasted load of the transformer. If the transformer is not in a critical utilisation, the grid fee is the same as the fix one. If the load is above a threshold, the grid fee is increased for the first time. If the nominal power is reached the grid fee is increased for a second time. So, the aim is to reduce load of the cost optimized flexibilities by higher grid fees. On the other side, if the generation is too high, the grid fee is reduced in the same manner to trigger additional load.

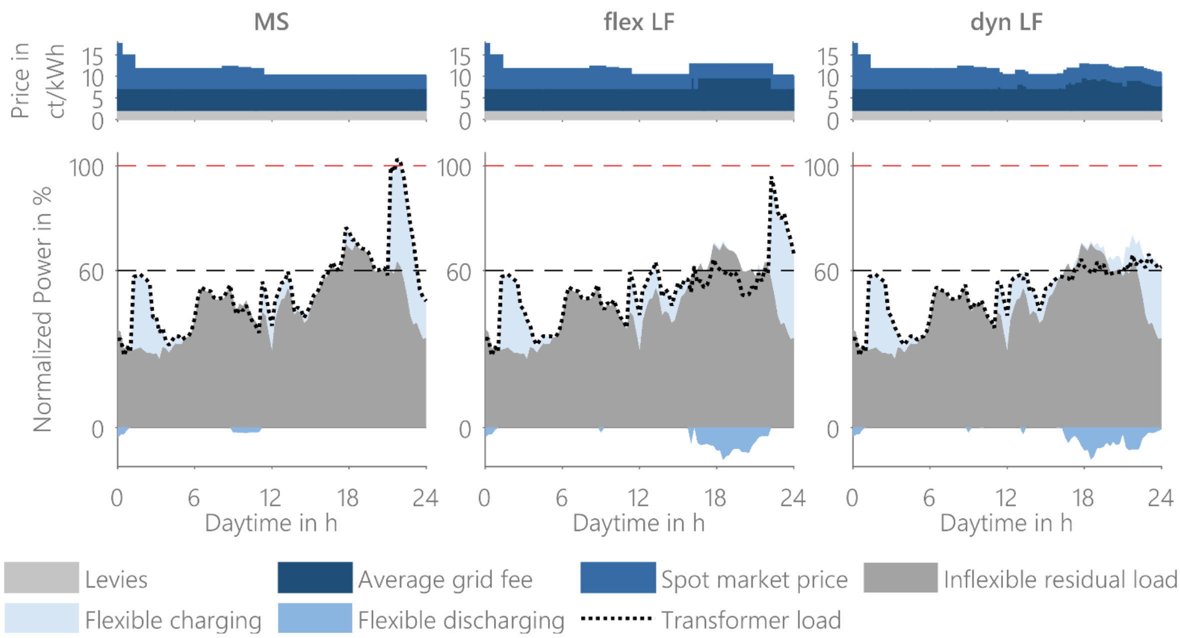

Figure 11: Grid fees and resulting loads for one overloaded grid. Left: Mixed scenario without variable grid fees, middle: variable grid fees with flexLF, right: variable grid fees with dynLF

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Figure 11 shows the methods for an exemplary grid. On the left side the grid fees are fix, in the middle the flexLF and on the right side the dynLF method is shown. On top the resulting prices for the flexible components are shown. Below that, die different load types are displayed. The inflexible residual load here includes PV generation, household and HP load, as well as the load of EV and SBS, which do not react to variable grid fees. On the left side, the transformer is slightly overloaded in the evening hours due to low prices and high availability of EVs, that need to be charged. With the variable grid fees (middle), in this case the threshold is set to 60 %, the grid fee rises from 5.05 to 7.58 ct/kWh if the load forecast estimates a transformer load above 60 %. This is shown between 5 and 9 pm. As reaction to the higher prices the EVs and SBSs are discharged. After the price falls to the normal level, the EVs are charged in times with lower inflexible load and therefore, no transformer overload occurs. In the scenario with the dynamic load forecast (right side), the average grid fee is smoother since the effect of the flexible loads is considered. This leads to a more constant gird utilisation around the threshold of 60 %.

Finally, the residual load is calculated based on the static and flexible load profiles at each GCP for each simulation timestep and the **load flow calculation** carried out by OpenDSS based on the Newton-Raphson method. As a result, voltages and currents in the grids are known and the grid status for different scenarios can be analysed.

Results

The different steps in the process of this case study are shown in Figure 12. Initially the 1206 grids were simulated based on the developed mixed scenario for 2040. As a result, 489 grids were overloaded, meaning that at least in one time step the nominal load for a transformer or cable was above 100 % or the voltage at any GCP was outside of the allowed range of ± 6 % of the nominal voltage [19]. In a comparative simulation, this time completely without EV, it was found that already in 300 of the 489 grids overloads occur only due to the inflexible loads, mainly due to HP. Since it is assumed that only 17 % of EV react to variable grid fees overloads within these grids cannot be solved through flexibility, so the sample was reduced to 189 grids.

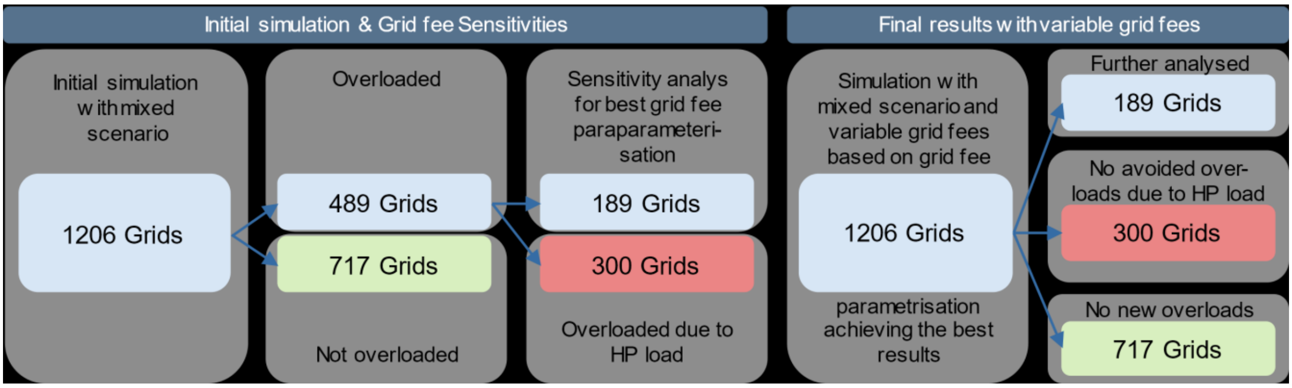

Figure 12 - Overview of the different sample sizes used in the process of the analysis

Based on these 189 grids parameters for the grid fee calculation were examined for sensitivity regarding grid relief to find the parameter combination with the best effect on grid relief. To analyse the effects of variable grid fees within the whole grid sample another simulation of the mixed scenario including the best parametrisation for variable grid fees was carried out to compare it with the simulation results of the mixed scenario without variable grid fees.

In the beginning the three possible load forecast methods inflexLF, flexLF and dynLF were analysed. The results can be seen in **Error! Reference source not found.** (A) showing the share of overloaded grids with the mixed scenario without variable grid fees as reference, where 100 % of the grid sample (189 grids) are overloaded. In 4 % of the grids the variable grid fee based on a load forecast consisting of inflexible, static loads lead to grid relief due to flexible EV and SBS. If the static EV load is considered in the load forecast (flexLF), the share of overloaded grids is reduced slightly to 93 %. The load forecast method dynLF leads to the most relieved grids due to the best estimation of the grid situation, because the local grid operator can estimate the grid load based on the reservations the costumers have to make for the load of their GCP. But even with a precise load forecast, 81 % of the grids remain overloaded.

To further analyse the cause, two parameters relevant to grid fee calculation were varied (B). Firstly, the grid fee spread (GF spread), meaning the level at which the grid charges increase when the transformer limits are exceeded and secondly, the transformer limits (utilisation limit) themselves. Within the varying load forecast a grid fee spread of 50 % and a utilisation limit of 60 % were chosen. Within the parameter sensitivities simulations were carried out with a grid fee spread of 15 % as well as 100 %, based on the best load forecast method (dynLF).

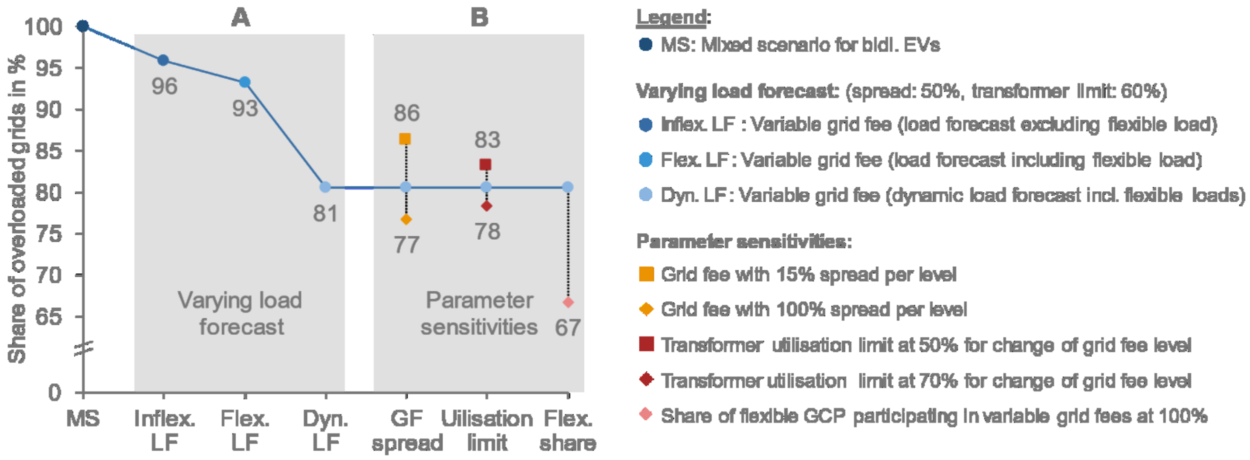

Figure 13 - Impact of different load forecast methods on the share of overloaded grids based on the mixed scenario **(A)** and analysis of three parameter sensitivities (spread per grid fee level, transformer utilisation limit and share of flexible GCP) based on the dynamic load forecast method **(B)**

The lower spread which results in a maximum of 6.6 ct/kWh is oriented to the costs of in total 30 % that fall back on operational management in the grids according to [20]. The 50 % spread leading to a maximum fee of 10.1 ct/kWh is roughly based on the currently common reductions of grid fees in Germany according to §14 a EnWG, which are offered if an electrical device can be switched of for a certain period [21]. A rising spread leads to slightly less overloaded grids and vice versa, with 77 % of overloaded grids remaining with a 100 % spread and a maximum of 15.15 ct/kWh.

Further on, a rising of the transformer utilisation level from 60 % to 70 % leads to 3 % less overloaded grids compared to the reference with dynamic load forecast. The fact that a higher transformer limit results in fewer overloads can be explained as follows. With a "later" increase of the grid charge level, there is an increased grid charge at fewer timesteps and thus more margin for an increase of the grid charge at the critical timesteps.

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The results of the sensitivity analysis regarding parameters relevant for the grid fee calculation show, that the best results on grid relief can be achieved by the dynamic load forecast in combination with a grid feed spread of 100 % and a transformer utilisation level of 70 %. To further understand why most overloads nevertheless occur, the share of flexible GCP (Flex. share) was increased to 100 % in a final sensitivity, so all EV and SBS participate in variable grid fees. This reduces the share of overloaded grids to 67 %. Since this sensitivity is assumed to be unrealistic, as all GCP would have to have the necessary infrastructure to participate in variable grid fees, this approach was not pursued further. At the same time, however, it can be excluded that the overloads cannot be resolved due to too few GCP participating.

With these parameters relevant for the grid fee calculation (Spread: 100 %, Utilisation limit: 70 %) the mixed scenario with variable grid fees for the whole sample of 1206 grids was simulated again to check possible negative effects of the variable grid fees on not overloaded grids on the one hand and to analyse the 300 overloaded grids due to HP for possible relief on the other hand. The result showed that neither previously not overloaded grids were overloaded nor that the grids overloaded by HP could be relieved. For this reason, the further evaluations refer to the sample of 189 grids.

Possible reasons for a high share of overloaded grids could still be voltage violations and line overloads, which are not considered in the grid fee calculation. For this reason, the mixed scenario is compared against the results of the mixed scenario with variable grid fees shown in Figure 14 and grouped by the reason of overload. As reference 100 % of the grids in the mixed scenario are overloaded due to line overloads, transformer overloads or voltage violations, with 66.1 % caused by load based overloaded transformers and 59.3 % caused by lower voltage violations. Line overloads just occur in 8.5 % of the grids in the mixed scenario and upper voltage violations as well as feed-based transformer overloads do not lead significantly to overloaded grids. A decrease of overloaded grids down to 76.2 % can be shown in the mixed scenario with variable grid fees. The best effect of the grid relief due to variable grid fees can be seen for the load-based transformer overloads decreasing down to 37.6 % compared to 66.1 %. The grid relief for voltage violations and overloaded lines is smaller, which can be explained by the fact that the grid fees are calculated based on the load forecast of the transformer.

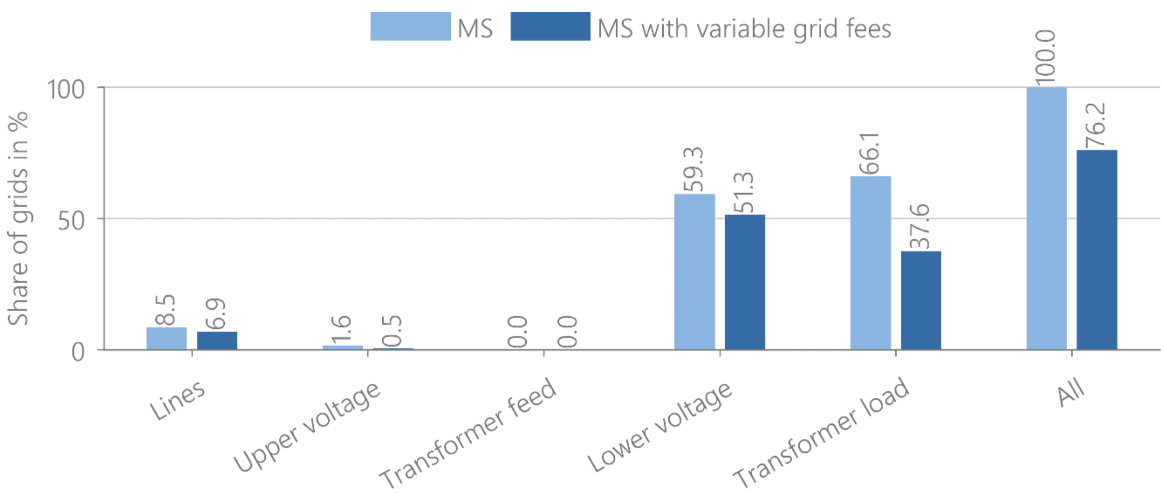

Figure 14 – Share of overloaded grids (189 grids in total) grouped by overload reason of the mixed scenario with and without variable grid fees and dynamic load forecast

To take a closer look at the effects in the grids that are not relieved, Figure 15 compares the hours with transformer overload for the 125 grids with overloaded transformers in the

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mixed scenario with and without variable grid fees. The figure is capped at a duration of 80 h as the first four transformers have higher overload durations in the mixed scenario (276 h, 119.5 h, 101.5 h, 95 h). In total, 56 transformers could be relieved by the variable grid fees with dynamic load forecasting and the duration of transformer overload could be reduced by 82 % on average. This shows that the variable grid fees also relieve the overloaded transformers to a certain extent.

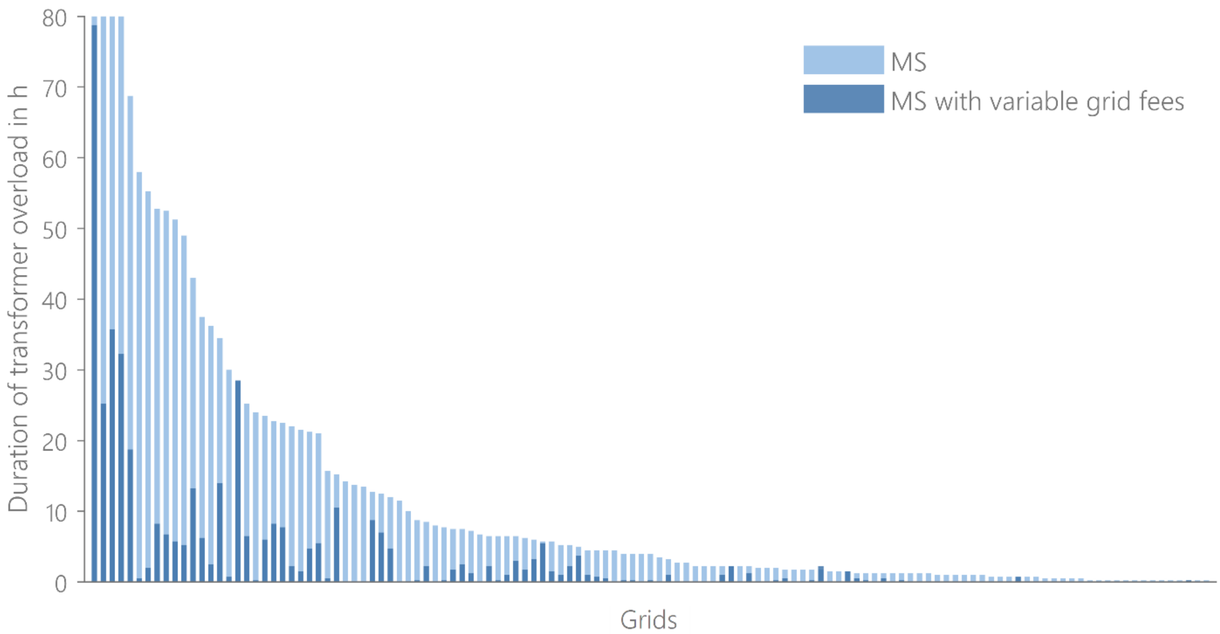

Figure 15: Duration of transformer overlaod with and without variable grid fees and dynamic load forecast

To analyse the financial impact on the grid operator and the customers, the grid fees for each GCP were calculated. From a grid operator's perspective, the relevant average grid fee weighted based on the amount of energy received from the grid is 4.86 ct/kWh across all 189 grids and varies between 3.2 ct/kWh to 5.63 ct/kWh. In return the grid operator can also transmit more energy through the grids due to the grid-serving consumer behavior. Whether the lower specific grid fees have a negative impact on the revenues of the grid operator cannot be answered due to the lack of a grid expansion analysis and the associated costs. At the same time, the median of customers with variable grid fees pays 3.39 ct/kWh whereas customers without variable grid fees pay 5.05 ct/kWh. The lower specific grid fees for flexible customers are due to the customers' ability to obtain energy at times of low load and feed it back at times of high load to remunerate the grid fee by the grid operator. This leads to lower grid fees especially when PV systems are available.

Conclusions

The simulation of the mixed scenario without variable grid fees showed that a total of 489 of the 1206 grids are overloaded and of these, 300 grids are overloaded by the inflexible additional HP load, which cannot be finally solved by the flexibility of grid serving EVs and SBSs. The sensitivity analyses for the remaining 189 grids have shown that using a dynamic load forecast, both a higher spread and a higher load limit led to more grid load reductions. In the combination of dynamic load forecasting, a spread of 100 % and 70 % utilisation, the share of overloaded grids is reduced to 76 % in the mixed scenario with variable grid fees. However, when the entire sample was simulated again, none of the 300 grids overloaded mainly by HPs could be relieved, even with the most effective parameters

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for grid fee calculation and load forecast. At the same time, the use of variable grid fees did not result in any new overloads in grids that were not previously overloaded. In the case of transformer overloads (125 of 189 grids), the hours with transformer overloads could be reduced by 82 % on average.

The fact that most grids cannot be completely relieved is due to several effects. On the one hand, in grids with high and long-lasting overloads, grid fees are high for several days at a time and thus lose their grid-serving incentive compared to the spot market price. Furthermore, the grid fee spreads can also be completely overlaid by the spot market spread, so that they are no longer significant. But even if many EVs and SBS are not traded simultaneously on the spot market (V2G) but react primarily to variable grid fees, the flexibility is not sufficient to completely relieve most of the grids. This is also since line overloads and voltage violations contribute to the share of overloaded grids but are not included in the calculation for the variable grid fees, as it is assumed that, from the grid operator's point of view, only a forecast of the transformer load is possible for the time being.

Since the focus of this work is on grid overloads caused by loads due to the chosen scenario further research regarding the effects in grids with overloads caused by distributed generation units, like PV plants, is necessary. Furthermore, in future not only EVs and SBS could react on price signals, but also HPs, leading to a higher flexibility. The design of variable grid fees also leaves further options for examinations. For example, more than three price levels can be selected, or voltage and line problems can be considered based on better grid condition forecasts. Also, the question, how cost-optimised consumers can contribute to avoiding grid expansion by using a grid-supporting price signal as variable grid fees needs to be further investigated.

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Regulatory support measures for smart grids and promoting flexibility

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Introduction

The energy sector is increasingly associated with the terminology "energy transition," and the main factors that determine and enhance this transition are the integration of renewable energy sources and digitalization. The smart grid concept par excellence is based on a series of real-time features and functionalities, by involving 5G technology, integration of algorithms for analysis and substantiation of decisions using big data, innovative services, and solutions to promote flexibility in the energy systems, responding to the challenges of managing the unpredictability of renewables.

In more and more fields, big data and in general digitalization is following a trend with a very high dynamic. In business, digitalization most often refers to enabling, improving, and/or transforming business operations and/or business functions by leveraging digital technologies and a broader use of digitized data, turned into intelligence and actionable knowledge.

The effective exploitation of this valuable source depends, to a large extent, on the quality of the data analysis, interpretation algorithms, and the associated ICT applications and cloud-based services for grid operation effectiveness and flexibility.

The development of such solutions and the wider analysis of the context of their implementation, addressed in a number of research projects such as edgeFLEX - Providing flexibility to the grid by enabling VPPs to offer fast dynamics control services [1], SOGNO - Service Oriented Grid for the Network of the future [2], and RESERVE – Renewables in a Stable Electric Grid [3], highlighted several aspects that need to be considered in order to facilitate the widespread adoption.

By default, and with technology advancement, the market reacts and proposes solutions to respond to these trends, but their adoption and implementation depends, to a large extent, on new measures and updates of the regulatory framework, to respond appropriately to both technical and market challenges.

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Regulatory measures to support smart grids and promote flexibility

Whether we are referring to technical or market challenges, in the context of adopting and implementing smart grid solutions and promoting flexibility, the regulations in force can be both important obstacles and catalysts for the adoption of these solutions.

The energy sector is certainly one in which historical data on the operation of energy systems have been collected to a large extend over time. Moreover, the trend and dynamics of digitalization consolidate this positioning of the energy sector towards real-time and big data solutions to exploit this huge potential, with an impact on better monitoring, control, and optimization of operations. With the increase of distributed energy and the challenges of integrating variable renewable energy, the main actors in the field, TSOs and DSOs, are increasingly able to collaborate and take on new roles. The trend of digitalization in supporting smart grid processes and flexibility by adopting and implementing real-time data driven solutions, also generates new actor profiles such as solution integrators, aggregators, prosumers, energy communities, VPPs and others who play key roles in this context of energy transition.

In general, business models that integrate and rely on these digital solutions that support smart grid development are service-focused, and regulatory actions aimed at supporting the cost of service can act as an effective lever in a "go to market" process.

In the same vein, when we refer to ICT solutions in the field of energy, to ensure the uniformity, transferability and sustainability of these actions, the inclusion of ICT requirements in the existing Network Codes may be another key measure to consider in the context of regulations.

Moreover, these solutions integrating specific features and having a direct impact on the flexibility of energy systems, may be adequately supported by additional regulatory provisions, such as a Network Code on Demand Response and Flexibility, as well as other measures which will be further described in this paper.

Regulations to support “Cost of service”

Intelligent energy systems for monitoring and operating energy networks relay on the adoption and implementation of ICT real-time big data applications, which at an advanced level can be outlined in intelligent machine learning solutions. In most "go to market" scenarios that are analysed in energy research projects, these solutions are integrated and defined in the business model projections as services.

Going further on these scenarios, the integrators of such solutions, as aggregators or other new profiles outlined in this context, become the providers of these services. TSOs and DSOs, as potential beneficiaries, need appropriate policies and regulatory framework to encourage the solutions acquisition technically and financially, and generally their adoption on the specific market.

An impactful regulatory measure, meant to become an important lever in the context described above, refers to the provision of incentives and support for "cost of service".

To a large extent, the national energy markets of many European countries already have regulatory provisions to encourage and support investments in the development of energy

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networks aimed at improving the quality of their operation, which are related to CAPEX. The same objective, of operational safety and increasing the quality of energy services, can be achieved more efficiently through a mix of CAPEX and OPEX solutions, the latter reducing the intensity of the financial effort that should be supported by energy market operators.

In a broader OPEX support framework, the policies to incentivize should consider hardware components such as sensors acquisition for better insights regarding electricity grid status, but also telecommunication solutions for implementation of faster and more reliable data transmission.

ICT chapter requirements and updates within existing network codes

In the same context and from the same perspective of regulation, an important aspect refers to ICT chapter requirements within existing network codes, and their dynamic update.

At European level, TSOs have a well-developed and well-founded regulatory framework. Most of the research work has been focused on a time perspective up to 2020, and on the implication of RES at transmission network level. However, it is widely accepted that much of the growth of renewables beyond 2020 may be based on decentralized generation. So far, no thorough analysis was done beyond transmission level, which means that the distributions networks are at the current state insufficiently analysed and tested, which may result in additional future challenges through unidentified behaviour.

Regarding transmission, the European Commission has defined a set of network codes with two associated objectives: the first leading to the completion of the EU internal energy market, and the second to achieve the 20% target for renewable integration by 2020. Therefore, this initial target of 20% renewable energy sources (RES) was the basis for the definitions of the current set of network codes, and the existing design components of the ancillary services are meeting the same criteria.

On the way to exponentially increase of variable renewable energy and digitalization, several technical and regulatory challenges need to be considered, and amendments to the existing network codes and ancillary services are necessary. It refers to a series of critical changes and adaptations, from a technical point of view, as frequency and voltage control, to support the stability, safety, and optimal operation of the energy system, with regulatory implications both from this perspective and from that of ICT aspects, as is the case of ICT chapter requirements within existing network codes.

It responds of course to the context of exponential increase in the degree of involvement of ICT technologies in energy solutions, to ensure primarily compliance with uniformity and transferability requirements, and properly supporting the main technical challenges:

- to enable new technics for voltage stability control in the power grid by connecting a huge number of communication end points in the future.
- to enable the new technique for online inertia estimation that will solve the current problems, i.e., decreased system inertia because of penetration of distributed energy sources.
- to enable the new technique for frequency stability control that will solve the existing power grid problems, i.e., to reduce the frequency variance.

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- to enable the advanced technique for optimization of VPP operations that will improve current energy market trading.
- to enable the advanced energy flexibility aggregation and trading system, i.e., the new interactions between energy market and DSO fast dynamics techniques that will further improve stability of the power grid.

Regulating VPPs as new participants to the electricity balancing market

Nowadays, the Electricity Balancing Market (EBM) is a very important component of the power systems operation. By the instrumentality of this structure, the power system operators are provided with the necessary tools for controlling the frequency, both in normal operational conditions and in case of outages. This is also critically required to improve the power balance in power systems with high penetration of non-synchronous devices.

Considering the importance of the EBM in current power systems operation, the requirements for acceptance as a participant are very detailed and strict. The status of participant allows the firms to make offers and receive payments on this market. Once a legal entity receives the status of participant on the EBM, its behaviour is carefully monitored by the power system operator, which is normally the EBM operator as well. In case the participant is not fulfilling its contractual obligations, the penalties start from financial fines and may go up to the cancellation of the participant status.

Until recently, the VPPs have not been considered reliable enough to be accepted as an EBM participant. However, the developments in the software platforms used for coordination of the VPP's components operation have led to a greater acceptance from this perspective.
There are disparate initiatives by national regulators belonging to different European countries to address the role and responsibilities of VPPs in this context, but without a consistent approach, guided by a set of good practices and providing sustainability.

The findings and results of the edgeFLEX project are aiming to consolidate this acceptance trend and allow the project members to promote VPPs as a valuable participant of the EBM in the power systems where this approach is not yet implemented.

New rules for the management of RES electricity generation

Starting from the example of such an initiative in Germany, where there are extensive changes ahead for grid operators in terms of redispatch and feed-in, the legislature has extensively revised the requirements for the curtailment of generation plants in the event of grid bottlenecks and voltage problems with effect from 01.10.2021. It refers to the management with the passing of the Network Expansion Acceleration Act 2.0 (NABEG 2.0).

In the future, all grid operators will be in position to solve their grid congestions using market-oriented actions, by providing financial compensations. In addition, new contracts will have to be drafted, negotiated, and concluded. The burden on each grid operator is expected to be high. All generation facilities, including RES plants and Combined Heat and Power (CHP) plants from 100 kW installed power, as well as plants that can be remotely controlled by a grid operator at any time (this essentially concerns controllable PV plants up to and including 100 kW installed power), are included in the redispatch.

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The implementation mechanisms for the redispatch of RES and CHP plants have also been redefined. In the future, the balancing group manager of the generation balancing group will be entitled to perform balance adjustments. In addition, the plant operator is entitled to receive financial compensation for the lost revenue, as has been the case in the past. In the future, shutdowns will be based on planned values and forecast data.

In the event of a grid bottleneck or voltage problems, the grid operator having this problem in the grid, must decide which generation plants in its grid or in other grids are to be curtailed to eliminate or avoid the problem. In addition to the effectiveness of the measure, the grid operator must also consider the costs caused by the curtailment (on both sides of the bottleneck, if applicable) as part of an overall assessment and form a "merit order" (deployment sequence) for the redispatch on this basis. The measures that are "expected to cause the lowest costs overall" are then to be selected. For Renewable energy plants and CHP plants, imputed (i.e., fictitious) costs are used as a reference in this respect. These imputed costs are determined with the help of a factor to be defined by the Federal Network Agency (BNetzA), which is to be selected in such a way that RES and CHP plants are only derated if otherwise five to fifteen times the non-priority generation would have to be curtailed. The factor can be determined differently for RES plants on the one hand and CHP plants on the other.

By applying this type of rules, adapted to the requirements of VPPs and standardization at European level, a new source of income is effectively created for VPPs and its components, and a sustainable impact on flexibility.

Network Code on Demand Response and Flexibility

In the same context described above, with reference to the exponential dynamics of RES integration in energy systems, there are not only requirements for updates and completions of existing Network Codes but also for new Network Codes to further address demand response and flexibility issues.

Through both the EU Green Deal and Clean Energy Package, the European Commission has committed itself to an ambitious CO2 reduction agenda. Decarbonisation and decentralisation increase the system's need for demand-side flexibility (DSF), which is urgently needed to make the energy transition possible and cost efficient. The Electricity Market Design Directive and Regulation remains a priority for the European Commission and European TSOs and DSOs, as they already contain valuable provisions to eliminate regulatory barriers to demand-side flexibility. Among others, the framework for the participation of demand response, including through aggregation, to all electricity markets, as well the principles of market-based congestion management, local energy communities and non-wire alternatives to grid extension, set ambitious measures for the inclusion of new actors to the markets.

At the EU level, the market for DSF is still fragmented, and almost non-existent as local level. A legally binding technical framework should be in place to properly complement the provisions set by the existing regulatory framework for the Electricity Market Design.

All of this supports the need for a Network Code for Demand Response and Flexibility. In this direction, synergies are already being created with relevant initiatives at European level, such as the Joint Task Force (JTF) composed of ENTSO-E and the four European

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associations representing DSOs (CEDEC, E.DSO, Eurelectric, GEODE), aiming to provide recommendations on the DSF Network Code, based on the report titled “Roadmap on the Evolution of the Regulatory Framework for Distributed Flexibility” [4]

This report analyses the regulatory requirements to integrate Distributed Energy Resources (DERs) into the grid and system services both at transmission and distribution level, providing analysis and recommendations in support of this approach, focused on topics divided into 4 clusters:

- Market access and rules for aggregation
- Product design and procurement
- Market processes and transmission and distribution (T&D) coordination
- Measurement, validation, and settlement of flexibility services

Source of well-founded regulations

The evolution of the power sector is a continuous process, with challenges, but also with answers given by the increasingly complex and effective solutions supported by the technological progress. A variety of distributed energy resources and improving computation, communication, and control technologies create an unprecedented degree of choice for DSOs and electricity consumers, choices that are poorly guided by incentives and other support measures from the perspective of regulations. Through appropriate regulations and policies, we must address both the technical challenges of the adopted technological solutions, as well as the market challenges that may arise.

The regulatory measures described above materialize in a set of recommendations for the effective support of applications and energy digitalization from the DSOs, TSOs and other innovative actor profiles perspective, within smart grid and flexibility context.

They should be also properly linked and respond to a set of key regulatory principles of the governance framework for future electricity networks, as described below:

i. Efficiency of the investments and costs

It is well known that in the power sector all the costs are in the end included in the energy price and therefore covered by the end-user. At the same time, maintaining an affordable and sustainable electricity price on long term is a major goal for all EU members. Under these conditions it is very important to optimize the adopted technical and regulatory measures to achieve the maximum impact for the safety in operation of the power systems, closely monitoring the financial impact as well.

ii. Collaboration at regional level

Natural resources are not equally distributed among EU members and therefore it is necessary to increase the collaboration beyond the national borders, to make full use of the existing capabilities. The cost for the activities necessary for the day-to-day operation of the power systems must be optimized at a regional level rather than national level as is today. Putting in practice of this principle will require in the first place the harmonization of the regulatory and legislative framework among EU members and in the second-place development of regional structures like control and coordination centers able to provide a proper resource transfer when needed.

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iii. Transparency and predictability

One of the most important results of the unbundling was the development of many companies and firms, private or state owned, linked together in a very intricate activity. In many cases, the economic interest of these legal entities was contradictory, or they were in a direct competition for providing services or resources. Obviously, the society interest is to support the development of those entities that are helpful for the power systems operation and to restrain the development of the entities that are only taking advantage of different administrative of regulatory mismatches, thus increasing for not good reason the electricity prices at end-user's level. Providing a transparent and predictable regulatory and legal framework will help the existing or potential investors in the power sector to develop business plans sustainable on long term and, as a result, the electricity price will be under control.

iV. Priority

Taking into consideration the complexity of the power systems and electricity markets operation and the challenges generated by the transition from nowadays situation to up to 100% RES it is very important to accurately identify the priority scale of the necessary measures. It is well known that a good rule may have bad results if it issued to early or may have no results if it is issued to late (or something in between) so the timing of the regulations is of outmost importance. A proper identification of the priority and sometimes urgency of a measure will bring benefits from both: time point of view (by reducing the overall duration of the process) and financial point of view (by effectively supporting the next steps and thus reducing the costs of the whole process).

V. Long Term Continuity

The energy transition process built on higher renewable energy integration, and digitalization needs to be designed and followed as a whole. Is necessary to make sure that measures taken in the first stages, although apparently useful at that moment, are not hindering the implementation of future stages by becoming obstacles that must be removed. In this way of thinking, every step must be coordinated with the existing and future conditions and necessities so that both to be answered properly.

Vi. Societal acceptance and involvement

Acceptance and involvement of the society must not be approached separately because they are synergically connected. Acceptance will bring more involvement and more involvement will bring more acceptance supporting in this way the development process towards digitalization. Based on the experience gained so far in implementation of several projects on digitalization of energy, the above-mentioned principles are not independent of each other and, they are connected in a hierarchical structure. The most important principle proved to be "Societal acceptance and involvement". Failing to follow this principle will, most likely, lead to significant difficulties in implementing the necessary measures, no matter how much they are justified from the technical and economical point of view. On the contrary, the action plans developed according to this principle proved to be much more easily and even cheaper to be put in practice.

The principles described above were the basis for the analysis and the algorithm for defining and substantiating the proposals for completing the regulatory framework. These

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have been subject to extensive consultations with all categories of stakeholders, including industry representatives, energy experts, policy makers and regulators.

List of acronyms:

ICT - Information and Communications Technology DSOs - Distribution System Operators
TSOs - Transmission System Operators CAPEX - Capital Expenditure
OPEX - Operating Expense
RES - Renewable Energy Sources VPPs - Virtual Power Plants
EBM - Electricity Balancing Market DSF - Demand-side flexibility
JTF - Joint Task Force
ENTOS-E – European Network of Transmission System Operators for Electricity DSOs – Distribution System Operators
CEDEC – European Federation of Local and Regional Energy Companies E.DSO – European Distribution System Operators

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Project SoLAR demonstrates real-time pricing based on grid state variables in grid cells

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Abstract

Future energy systems based on 100% renewables require new approaches to balance generation and consumption and mitigate congestions. The living lab SoLAR demonstrates a new approach in a real housing quarter. It was presented at GSM 2020 by Easy Smart Grid, which develops the basic technology. Here we present potentially standard solutions for decentral energy markets and corresponding energy management developed during this project, and their expected benefits. SoLAR uses the “cellular grid” approach and a market platform enabling reactions from flexible consumers and generators depending on grid situation. In contrast to traditional approaches, prices are not derived by negotiations and schedules on different market platforms, but directly and in real-time from local grid states.

The concept splits energy tariffs into two components: a fixed refinancing component, covering average generation, sales and grid costs, taxes, levies etc., and a dynamic component to coordinate all participants or cell users in operation. This dynamic price component is derived from grid state values representing energy balance and/or congestion. Thus, grid operator needs are translated into a financial stimulus for flexibility provision by end customers. For short term grid balancing, grid frequency is sufficient to determine and communicate a dynamic price component. The ENTSO-E grid can be considered as convoluted cells. In the absence of congestions, state differences of sub cells can be ignored. If necessary, the concept can be extended, e.g. by using the ACE of a control zone.

In SoLAR, rooftop PV, heat pumps, CHP, electric vehicle charging as well as household appliances are successfully coordinated by a price signal derived from the quarter’s residual load to maximize self-consumption and minimize grid load. A simulation by EIFER suggests that household fridges and freezers, reacting to adequate price signals, could provide 100% of currently procured control power and about 75% of aFRR control energy. Project partners, including white-goods supplier BSH, will outline a proposed solution including potential roles and interfaces between grid operators, end customers and household appliance/energy management solution providers. The proposals also include fall-back strategies ensuring control by grid operators should market mechanisms fail to achieve the necessary reactions.

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Introduction

A climate-neutral energy supply with 100 % renewables has been proven necessary, and the corresponding transformation of the energy system must take place at very high speed. This requires a paradigm shift. The energy supply is largely electrified, with solar and wind as the predominant sources. These sources are not always available at the same time as demand and can only be influenced by financially lossy power plant curtailment. Balancing supply and demand through batteries and hydrogen technology is materially expensive, costly, and reduces system efficiency through conversion and storage losses. The demand for renewable energy becomes much higher than the actual used energy. [1]

To reduce the required storage effort as much as possible, the key option remains customer-side flexibility, which has contributed little to flexibility in the fossil system. Flexibility on the consumption side was provided by a few large industrial consumers and, in a greatly simplified framework, by electrical heating systems to ensure the utilization of power plants during periods of low consumption. In the electrified scenario, new flexible consumers are added, essentially electric vehicles and heat pumps. However, there is also a great deal of potential for flexibility in conventional electricity consumers such as household appliances [2] and industrial processes [3], although this is hardly ever exploited. Priority is always given to user needs and process reliability.
In the following, the current hurdles in the use of flexibility and a solution for raising the flexibility potential are described.

1. Requirements for Grid Services - Technical & Market Conditions

While the theoretical potential for flexibility is very high, the corresponding framework conditions, in particular the design and regulation of electricity markets and grid access conditions, are in great need of adjustment.

In particular, the regulation of grid charges allows even large industrial consumers to provide flexibility only to a limited extent, since power peaks that serve the grid may lead to a massive increase in electricity purchase costs due to higher grid charges. At the same time, the energy only market does not take into account existing grid restrictions, so that re-dispatch is increasingly necessary to protect interconnection points from overload. The costs for this amount to about 200 million euros per year in Germany alone. [4]

The change in energy production locations, from large power plants at the high and extra-high voltage level down to small, decentralized plants in the distribution grids, is also increasingly pushing the grid infrastructure to its load limits. Although flexibility has great economic potential as an alternative to grid expansion, the current incentive regulation tends to hinder its use. [5]

Electricity market and grid must therefore be thought of closely together, and integrated markets for trading, grid balancing and grid management are needed. In conventional energy markets, suppliers and buyers trade with each other through requests and bids on trading platforms. Subsequently, the future balance found on the basis of forecasts is executed via schedules. Since forecasts never arrive exactly, real-time is approached through various ex-ante trading levels: Forward contracts, day-ahead contracts, intraday contracts, and re-dispatch. The provision of control energy then follows in real-time.

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Finally, the transactions have to be verified by measurements and renegotiated ex-post. Simultaneous trading at different levels enables operators of flexible large fossil power plants to engage in so-called Inc-Dec gaming, e.g. by artificially inducing grid bottlenecks via the energy market, which are then profitably exploited by the same provider in re-dispatch. In the course of the transformation of the energy system, the market chains are becoming increasingly complex and in some cases form artifacts to the disadvantage of renewable energies. [6]

The current market system is only poorly suitable for activating small-scale flexibility, since it was originally designed to coordinate a few large-scale power plants and large-scale consumers and de facto sets small-scale consumption as a standard load profile in the market at the beginning of the year. With the help of smart metering systems and peer-to-peer trading platforms, attempts are being made to map the principle of the wholesale market onto private prosumers [7]. From the authors' point of view, this is doomed to fail on a large scale, as the number of necessary contracts increases as the square of the number of participants, and reliable schedules for small devices cannot be created. The aggregation of many participants is theoretically an effective means, but it also suffers from massive increases in complexity and the effort required for communicative connectivity. There also remains the limited plannability of availability - in addition to the uncertainties due to the fluctuation of renewable energy sources. Operators of industrial processes, in particular, are therefore massively opposed to having their plants controlled by third parties, and for good reason.

2. Approach towards Flexibility and Business Experiences and Success Stories

Easy Smart Grid GmbH has patented a technology that is suitable for making the energy market of the future fit for the flexibilization of devices, regardless of their number, power, operating time and availability [8]. Control always remains with the user or system operator. In emergencies, operating states can be specified by the grid operator via an adapted transmission code.

The technology uses the "cellular approach", which was discussed, among others, in the working group "Cellular Energy System" of the VDE [9] and investigated in the project "C/sells" [10] within the SINTEG program of the German government. The cellular approach divides the grid into cells - defined areas of the power grid whose energy balance can be physically measured - at the various voltage levels. The aim with C/sells was to match generation and consumption as early as possible in a cell and to balance out any remaining imbalances between the cells. This divides the complex structure of the grid into smaller units that can be controlled by automation technology. Aggregation is thought of in spatial units that can also function decoupled from the rest of the grid in emergencies.

The core idea of Easy Smart Grid is that market participants use the measurability of the grid state of a cell directly for their trading transactions. In a grid cell that is coupled to an external grid, the energy balance within the cell can be measured in real-time by simply measuring the coupling point(s). Easy Smart Grid conceptually links this measurable grid state to the market price: if electricity is exported to the outer grid or the residual load is below a target level, the price in the cell is too high - too much production and too little consumption is stimulated. If electricity is imported or the target value of the residual load is exceeded, the price is too low. Since the deviation from the equilibrium price can be

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determined in the shortest possible time via measurement, the price can be quickly corrected and communicated to the market participants. In an isolated cell, e.g. a micro grid or an island with its own power supply, the energy balance is directly reflected in the power frequency, which can be determined anywhere in the grid by simple measurement.
This creates a real-time, physics-based pricing system that can potentially integrate all existing markets and in which ex-ante and ex-post negotiations are unnecessary. Contracts are concluded by simply switching on or off or modulating power. The current real-time price for a measurement period applies which is determined in parallel with the power in the meter of a grid terminal and assigned to the energy turnover. The future development of the price can be taken into account via forecasts.

It is proposed to use a "balance indicator" (BI), which reflects the grid state in a normalized range, e.g. -1 (max. energy scarcity) to +1 (max. energy surplus), as an intermediate stage to generate and communicate an abstracted price signal, which - depending on the energy supplier, network area and regulatory boundary conditions - can be converted flexibly and adapted to the situation into electricity tariffs and charges. The use of a normalized signal also allows the implementation of a real-time market without actual billing. Market participants then interpret the BI as an abstract currency with which they optimize their operations. High BI means low prices, low BI means high prices. Since most devices are "must run" oriented, the actual tariff level is irrelevant for optimizing operations; the decisive factor is to operate as "cheaply" as possible. [11]

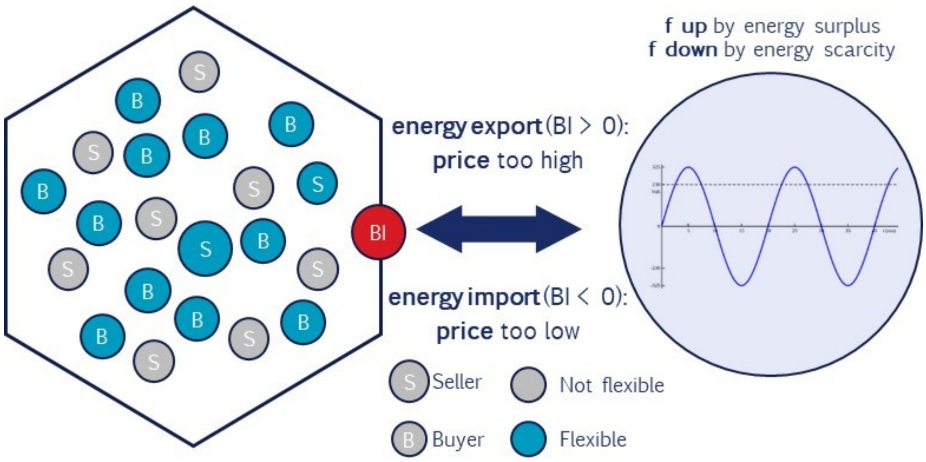

Fig. 1: Principle of price building by grid state measurement in grid cells

In a demonstration project at a property with 25 residential units in Allensbach on Lake Constance (Germany), the technology was successfully implemented for the first time together with renowned partners from research and the energy industry. The "SoLAR" project was funded by the Ministry for the Environment, Climate and Energy Economy of the State of Baden-Württemberg. The plant went into operation in 2021, and the systematic application of the market system for intelligent control is nearing completion (as of July 2022). [12]

In a cluster of 12 semi-detached houses and 3 multi-family houses, one of which is an existing building, decentralized heat pumps are installed in the individual houses, while the multi-family houses are supplied with heat centrally by a CHP unit. The CHP and 2 PV systems are operated by a utility and supply the property with electricity as part of a neighborhood power model. The semi-detached houses also have private PV systems for self-supply, some with battery storage. Surplus PV electricity is purchased by the utility

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and, where possible, sold on to the other customers in the complex. CHP units and heat pumps are intelligently controlled via Easy Smart Grid technology, as are residents' charging stations for electric vehicles and smart home appliances (dishwashers, washers and dryers, as well as refrigerators and freezers). In total, about 60 appliances are flexed in real terms in the property, and in a simulation there are even more than 140. The control is performed externally via one software agent per appliance in micro controllers, connected to each other and to the measuring points for the grid status and the status of the flexed appliances via Ethernet and serial interfaces.

The property's power grid is a customer facility that forms a grid cell and is connected to the public utility grid via a property meter. At this point, a BI is formed and sent to the control agents of the flexible devices, which then optimize their operation. The semi-detached houses with their PV systems form their own subordinate cells with their own BI, formed at the house connection, which is combined with the central BI of the property. The response of the heat pumps and household appliances in the semi-detached houses to the combined BI maximizes both household and property self-consumption. The BI signals are not converted into dynamic tariffs; nevertheless, the response of the appliances results in a significant increase in the share of self-produced electricity, thereby reducing the electricity costs in the neighborhood by about 5 €Cent/kWh.

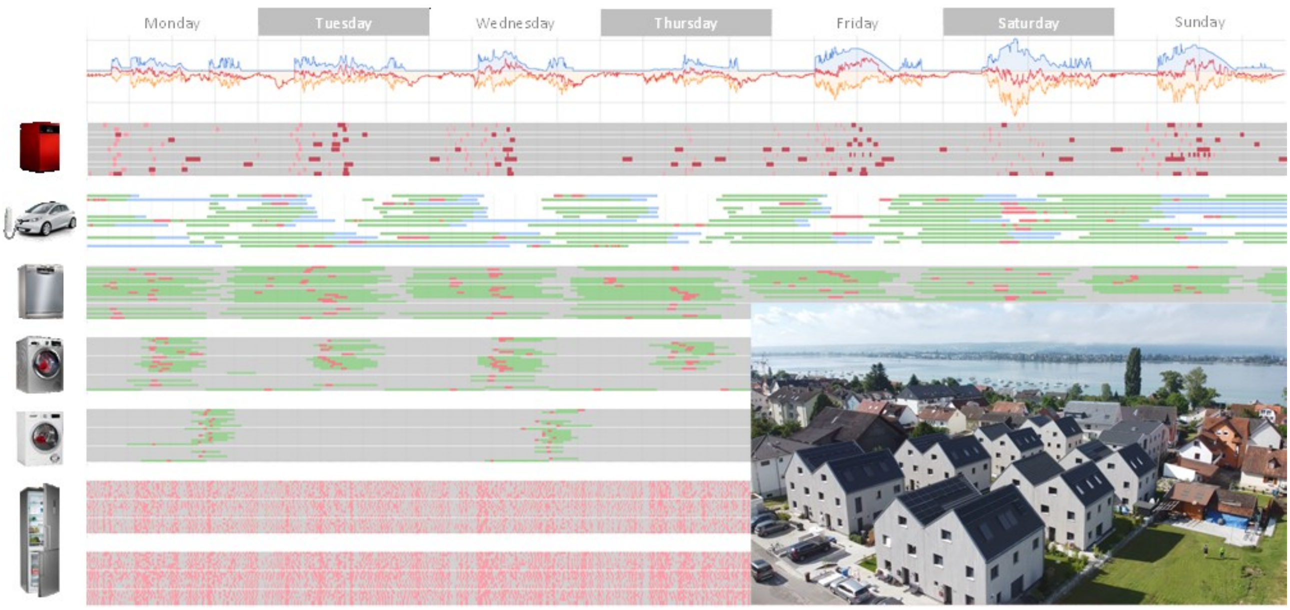

Fig. 2: Intelligent sector coupling in SoLAR, spring scenario
Top: total generation (blue), total consumption (orange), residual load / BI (red)
Operations: red, salmon = device active, green = process period (device available)

The European Institute for Energy Research, EIFER, in Karlsruhe, Germany, founded by EDF and KIT, has developed a novel "Virtual Demonstrator" VD for SoLAR that maps the property as a digital twin in detail and with high temporal resolution (seconds) in the simulation. This allows for precise pre-planning of real-world implementations and detailed analysis for context-specific scenarios to increase efficiency and climate friendliness. The VD is modular and parametric and is available for future research projects in the field of smart sector coupling. With the help of the VD, the algorithms for controlling the devices were tested extensively before real commissioning. [13]

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The measurement data in the real implementation match the predictions very closely. In addition, the VD was used to quantify the effect of flexibilization precisely before commissioning. The system based on real-time price signals has proven to be very effective. For example, the self-consumption rate can be increased from about 54% to 72% by flexibilization alone (without considering battery storage). In the simulation, the power peak in the grid supply was reduced from 85 KW to 50 kW, and in the case of the output to the grid, the peak was reduced from 83 kW to 60 kW. There is still potential for improvement in optimizing the charging processes for the electric vehicles. Since the vehicles are very often charged overnight, intelligent control in the current scenario contributes significantly to peak load reduction, but not significantly to increasing self-consumption. This shows the importance of using cells of sufficient size and diversity to incorporate as many and as diverse flexibilities as possible. If the vehicles could be charged mainly during the day, e.g. at the workplace, the self-consumption rate would increase to over 80%.

BSH GmbH (Bosch-Siemens-Hausgeräte) is the market leader for household appliances in Europe and has provided its expertise and 18 fridge-freezers for the project free of charge. BSH has an environmentally oriented management and is very interested in a new market design and technology that makes the use of flexible household appliances grid-friendly and profitable for the users. Household appliances in Europe cause 382 TWh of electricity consumption (2017), of which more than 280 TWh can be made flexible in principle [14].

A particular focus of the research was on refrigerators and freezers. Although their power is relatively small and the energy shift potential relatively low, the appliances are available around the clock and thus could make a significant contribution to the provision of balancing energy. In a previous study involving BSH, the potential for power provision of control energy by household refrigerators and freezers was determined at 2.4 GW in both positive and negative directions [15]. Accordingly, the VD showed that the contribution to increasing the self-consumption rate is small, but the load curve is smoothed clearly. Jumps in the residual load are significantly dampened by counteracting responses of the refrigerators and freezers. Knowing the potential, a control concept for cooling equipment based on the grid frequency was also developed and patented by EIFER (EDF) before SoLAR [16] [17].

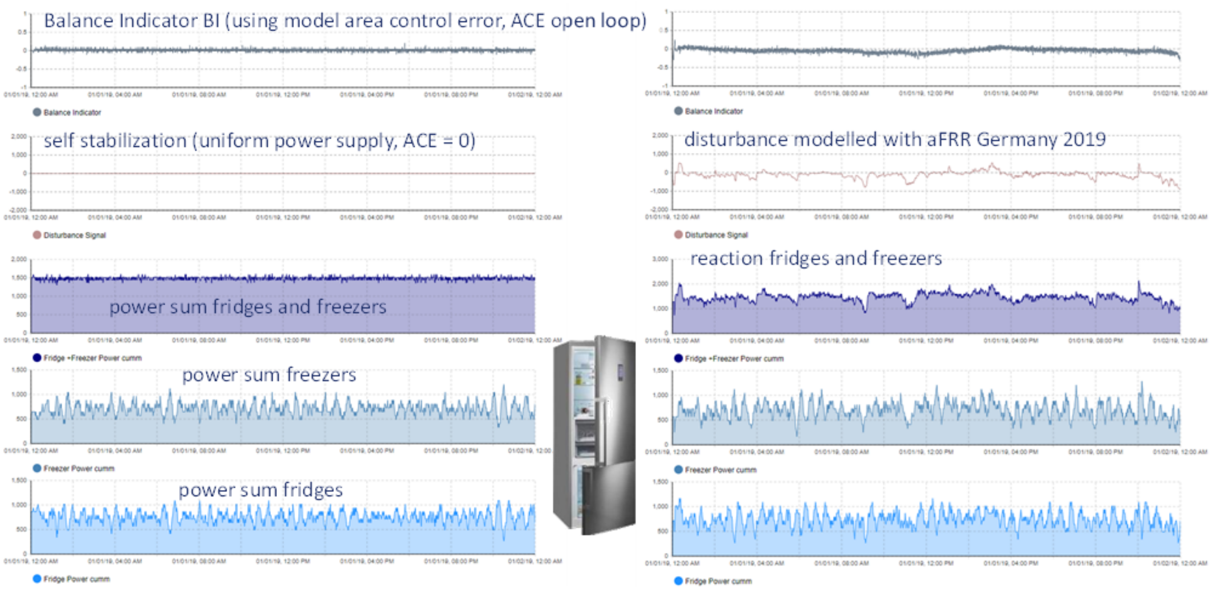

Fig. 3: Control area model with fridge-freezers

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As part of SoLAR, the potential for providing control energy was investigated in more detail using 23 refrigerators and freezers each from the VD in a separate model. This was done by first providing the average power of the appliances in the model of about 1500 W uniformly by a simulated power generator. The deviation between power output and uptake forms the ACE (Area Control Error) of this modeled control area. From this, a BI was formed. In response to the BI, the cooling units consumed exactly the sum power of 1500 W permanently. The deviations corresponded only to the power jump in the energy balance when activating or deactivating individual compressors. In order to simulate the provision of control power, the power of the generator was varied in such a way that its fluctuation corresponded to the scaled call-up of secondary control power (aFRR) in Germany in 2019. As a result, the devices followed the generator's fluctuations very closely in their consumption and reduced the ACE back to zero to a large extent as long as no temperature limits were exceeded. From the simulation, it can be concluded that the complete control power and 75% of the control energy could be provided via refrigerators and freezers in households alone.

The very positive results have encouraged the project partners to think bigger about the system and to leave the framework of customer facilities as cells. To this end, the concept of a roadmap has been developed on how the real-time market system can be gradually transferred to higher voltage levels. It is proposed to initially embed the system into the existing power system with as little effort as possible and then expand it in an evolutionary fashion.

As a first step, cells could be established in the medium voltage level of the distribution grid whose power balance can be measured at converter stations and, if necessary, coupling points between regional distribution grid cells. This allows the distribution system operator (DSO) to provide energy suppliers in the cell with a BI on the basis of which renewable energy communities in particular can be formed: Grid connections with flexible devices use the BI as a control signal. In response to the BI, the residual load of the grid cell is equalized. The feed-in to the high voltage decreases, as does the energy draw from the high voltage. The self-consumption rate in the distribution grid cell increases, the high-voltage level is relieved and the grid charges for the purchase from the high-voltage level for the DSO decrease. Renewable energy communities thus need to purchase less power from the external market. The forecast schedule deviation from the planning via standard load profiles and generation profiles can be eliminated in the balancing group management via a quantity balancing between the differential balancing group of the DSO and the balancing groups of the energy communities. The existing markets are not affected in this step.

If there is sufficient controllable flexibility in the cell, the DSO can use it directly to manage its differential balancing group and minimize real-time deviations from the forecast balance via an adequately formed BI. This reduces the costs for balancing energy and the DSO can significantly increase its balancing group fidelity. Now it is even conceivable that the flexible cell can be prequalified for the provision of balancing energy and re-dispatch. To promote renewable energy communities with flexible grid participants, the savings to the DSO should be largely targeted to promote the energy communities whose flexibility is the source of the savings.

The low-voltage cell level, which was designed in SoLAR as a neighborhood with increased self-consumption, can be defined in the flexible distribution grid cell scenario as a grid area below one or more local grid stations. The goal would be to form another price

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signal, "Congestion Indicator" (CI), for this in times of possible congestion of local network strings. The CI only deviates from zero when the load of the network string approaches critical values. If there is no congestion, the combined price signal of BI and CI in the low voltage cell is identical to the BI in the medium voltage. The use of this price signal would be a solution that could resolve the conflict between the ideas of grid operators and representatives of market solutions - such as the automotive industry with regard to the use of charging infrastructure - when designing regulations for controllable consumption devices. The grid operator, as the responsible party, provides a price signal that can be used to design markets for congestion management. In borderline cases, the price signal can also be designed directly as control requirements for devices according to certain security classes, which are then disabled or throttled according to the specifications of an adjusted transmission code. Since the market system manages the bottleneck beforehand, this case is used only extremely rarely.

The design of a dynamic electricity tariff based on the technology can be done in such a way that the energy supplier initially sets a base price for electricity purchases, mainly from renewable energies and CHP, for its balancing group based on contractually fixed procurement costs and forecast market transactions. To this is added a base grid fee from the DSO that, as described above, takes into account the grid serviceability and controllability of a grid terminal. The tariff also includes state-determined levies and taxes. The total forms the base or refinancing price for electricity, which is based on long-term planning. By responding to BI and CI, an additional coordinative tariff component is formed that reflects real-time grid conditions and has sufficient variation to provide enough incentive to provide the necessary flexibility. This component can be a dynamic electricity price, which is in line with current regulations, or a dynamic grid fee. The latter is currently not possible from a regulatory point of view, but would be particularly easy to implement, since it would apply uniformly to all grid users in the affected cell. Dynamic levies or similar are also conceivable.

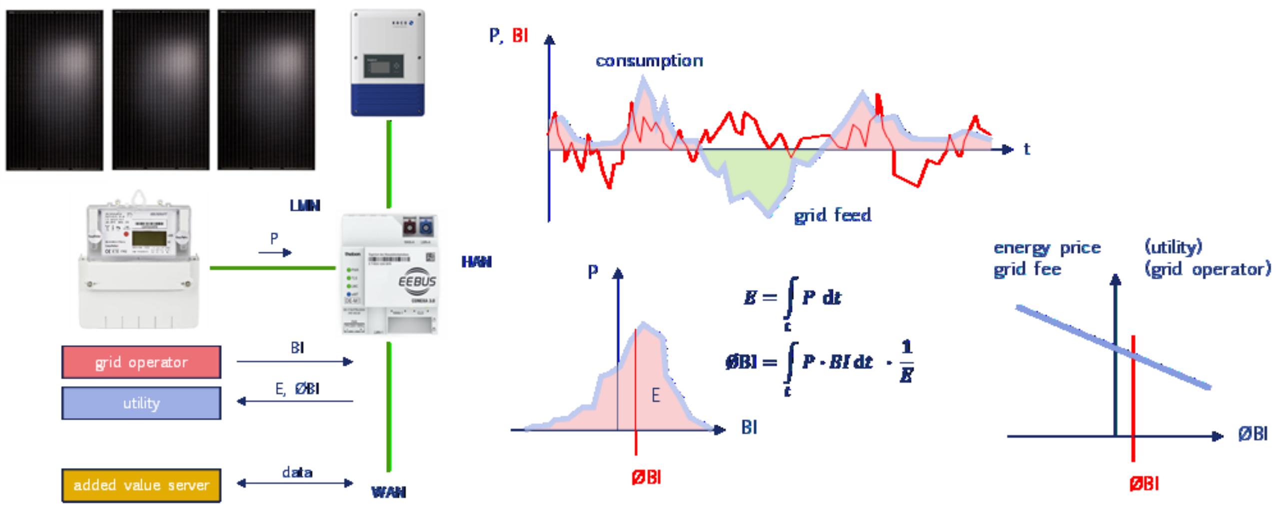

Fig. 4: Billing dynamic tariffs with BI

In terms of metrological implementation, the (combined) price signal BI in a cell can be determined or received by smart metering systems with high resolution in parallel to the power at the grid connection. The energy purchase is conventionally calculated by integrating the power over the billing period. If, during integration, the power is weighted by the current BI and the result is then divided by the energy quantity, the average value of

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the BI is obtained, which can then be used to easily determine the tariff via a linear function or table. Via a histogram of the energy quantities over BI classes, the grid-serving behavior of the grid connection can be documented and assessed without having to transmit load profiles. The same applies to the billing of dynamic feed-in tariffs.

The cellular power system can be further conceived and developed in regulatory terms step by step. In a further stage, a BI could be defined for the control area of the transmission system operator (TSO). As described in the example of the simulation with the cooling units, the BI can be formed from the ACE. This extends the approach of "Passive Balancing" or "Smart Balancing", as already applied in the Netherlands and Belgium, so that not only energy suppliers but individual prosumers can support the control area and be appropriately compensated for it [18]. At the transitions from high to medium voltage, only CI would be used in this scenario, so that a uniform price signal prevails in the control area, unless congestion needs to be managed. In this scenario, it is already possible to deviate from the required balancing group loyalty of the previous system.

The last step would be to directly use the power frequency as the basis for the BI. The control areas would then also only be priced via a CI, which would only become active if congestion at interconnection points had to be managed. In principle, balancing groups are now no longer necessary; trading could be organized entirely via the price signals, since the prices comprehensively reflect the energy balance. The associated tariff values could, for example, be set annually by ENTSO-E according to defined criteria.

The grid frequency as a price signal can easily be measured everywhere and is in principle unassailable. Frequency could also be used as an additional price signal in the first stages of the roadmap. The prosumers could support the frequency in case of appropriate formation of an additional BI. In case of communication failure, the affected cell, possibly in a decoupled state, can continue to operate stably by relying on the frequency as a basis for a price signal.

To increase resilience, it is proposed to operate regional grid cells, which are determined based on high correlation of weather data, in a frequency-decoupled manner when there is a bottleneck at the coupling points to the environment. This eliminates the need to communicate the deviating cell price; it can be derived directly from the grid frequency. The possibility of frequency decoupling also means that cascade effects in the event of frequency jumps in the overall grid can be reliably intercepted, and the transition to island operation in emergencies and subsequent feedback are possible without any problems.

3. Added Values/Conclusion

The SoLAR project has successfully demonstrated that a real-time electricity market based on price signals from the measurable energy state of grid cells is fully functional, easy to implement, and relatively simple and evolutionary to integrate in the existing system. The target scenario is the formation of a nodal system that provides a uniform price signal to balance supply and demand throughout the grid, which can be temporarily varied locally when congestion occurs. The system is potentially capable of integrating all existing energy markets and solves the previously open issues in activating flexibility for the energy transition in terms of transaction costs, resilience, and data security.

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Arguments that price security suffers under the system can be countered by the fact that in the current system price security after conclusion of the contract is only given in the respective trading segment. Due to the necessary subsequent transactions up to real-time and ex-post, the actual costs for the electricity purchase or the sales revenue deviate more and more from the long-term fixed price. The uncertainty is thus comparable to the real-time system. Planning reliability can also be achieved in the real-time market by means of forecasts of the expected price development and hedging transactions. Due to the significantly lower complexity of the real-time market, it can be assumed that the price certainty in the scenario with 100% renewables is even significantly higher in the real-time market. For price equity, this is to be expected in any case.

Good initial steps include the formation by DSOs of regional cells to support renewable energy communities, and contracts between TSOs and manufacturers to support primary reserve (FCR) through device response (in particular refrigerators and freezers) to a BI based on grid frequency. SoLAR partners are available to provide further guidance.

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Digital Assets Mining Hardware as a novel business model for system operators in the energy markets

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Abstract

This paper provides the foundation for the novel type of business model that connects digital ecosystems to the electricity market by integrating Digital Assets Mining Hardware (DAMH) in the power system based on the optimal allocation algorithm. DAMH is a large-scale flexible energy consumer that provides flexibility and stability to the power system while controlling reverse power flow (RPF) and additionally generating a secondary revenue stream for the power system operator and market participants. Due to a surge in electricity market prices that started during the second half of the previous year and still lasting today, need for a solution that merges operations of power system, electricity market and digital ecosystems like provided in this paper could prove to be necessary for future development of power systems. Due to the newly form situation with gas supply and prices, rapid and widespread integration of renewable energy sources (RES) entering the electricity market in Europe is inevitable. Already well-known volatile energy supply from RES is a variable in the electricity price forming process on the energy markets. Pandemic has also greatly impacted energy markets and global events like these are predicted to be more frequent in the future due to the climate changes. All of these creates such a volatile system where load reduction such as demand response (DR) programs are needed to keep the system in balance. DR programs can participate markets through ancillary services, such as frequency regulation using manual frequency restoration reserves - mFRR. Unlike typical energy consumers participating in DR programs, the DAMH can provide system operator a novel way to balance the system without interfering with the daily activities of the small consumers or the business processes of the large ones. Positive impacts from proposed solution by this paper are threefold, compensation for participating in the ancillary services market, reward in the form of digital assets and maintaining the balance of the power system.