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Business Models of Virtual Power Plants (VPPs) in Germany

Sino-German Energy Partnership

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Imprint

The report "Business Models of Virtual Power Plants (VPPs) in Germany" offers key insights about the development of VPPs in Germany and its contribution to power system flexibility, through conducting case studies of VPP business models and analysing the key power market and regulatory framework, in which VPPs are embedded; 2) reflects on key enabling factors for VPPs in particular, for its flexibility provision, in Germany. The report is published in the framework of the Sino-German Energy Partnership, commissioned by the German Federal Ministry for Economic Affairs and Energy (BMWi) and supported by the National Development and Reform Commission of China (NDRC) and the National Energy Administration of China (NEA). The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH implements the project under commission of the political partners.

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Executive Summary

Germany aims to achieve climate neutrality by 2045. Expanding renewable energy is a key pillar to achieve this ambitious target, in which wind energy and PV will play a dominant role. Given their intermittent character, the high penetration of wind and PV in the power system imposes significant challenges for grid operators and power markets to balance supply and demand. At the same time, decarbonisation of all end use sectors is associated with increasing electrification, which would result in a substantial growth in gross electricity demand and peak demand. Thus, power system flexibility is key for achieving climate neutrality in Germany. Virtual Power Plants (VPPs) have emerged as a promising solution here. It is a collection of distributed energy resources (DERs) that are centrally coordinated. DERs consist of small- to medium- scale resources that are connected mainly to the distribution grids or near the end users, including distributed generation, demand-side resources, and energy storage. Despite their potential of flexibility, they are often too small, scattered, and/or their power generation is too fluctuating to directly provide system service. A VPP, acting as an aggregator, will bundle these DERs into a sizable portfolio as a single resource. It monitors, forecasts, optimizes, and dispatches their generation, storage/release, or flexible consumption through a central IT system to enable them to participate in power markets and/or deliver the flexibility to system operators.

The study 1) offers key insights about the development of VPPs in Germany and its contribution to power system flexibility, through conducting case studies of VPP business models and analysing the key power market and regulatory framework, in which VPPs are embedded; 2) reflects on key enabling factors for VPPs in particular, for its flexibility provision, in Germany.

What are the requirements for VPP business models?

- Given the large pool of energy assets, VPP needs an ***advanced ICT software platform,*** which allows a large number of DERs to connect. The platform should be able to ***capture data***, ***enable secure and fast communication*** between VPP, individual assets, the grid operators, and electricity market, and ***automatically regulate*** the DERs to participate in electricity markets and provide grid congestion service. It relies on ***advanced forecasting algorithms*** to develop an optimised dispatch schedule.
- ***Hardware***: Real-time data capture from, communication with, and controlling of DERs in the portfolio requires ***smart meters, remote control, and automation systems.***
- ***DERs* in the portfolio:** In order to increase revenue, it is important to build a ***diverse set of DERs (generation, demand, and storage)*** and ***explore business opportunities on different markets.*** ***Biomass/ biogas power and hydropower*** plants are considered as ***indispensable resources*** for VPPs in Germany due to their high flexibility. ***Small-scale DERs,*** *such as BEVs, heat pumps, home storage*, rooftop PV, will play an increasingly important role in flexibility of the future power system. ***Green hydrogen electrolysis plants*** can also provide short- and long-term flexibility similarly to biogas power plants.

What is the enabling environment for VPPs in Germany?

The power market and regulatory framework in Germany have created favourable conditions for VPPs to provide flexibility services:

- The German government aims to prepare renewable power plants for the market, in particular, through the ***direct marketing obligation for medium-sized plants***. This created a key service area of VPPs in Germany. In addition, the ***unbundling*** of the vertically integrated power supply system establishes a fundamentally positive environment for new entrants, including independent VPPs.
- The German electricity market allows electricity trading ***close to real-time*** (***intraday market***). The shorter lead-time creates additional demand for rapidly controllable flexibility

available at a short notice, which can be provided by VPPs from their pools.

- With the ***balancing group approach***, transmission system operators (TSOs) need to purchase balancing energy from the balancing market, on which VPPs can offer flexibility from the assets they aggregate. In addition, a ***single balancing market*** enables balancing service providers such as VPPs to provide balancing services to all TSOs, which increases business opportunities for VPPs.
- The roles, market opportunities, and obligations of aggregators (VPPs) are ***legally defined*** in the German energy law.
- ***VPPs' access to markets***: Both European and German regulations ensure VPPs' access to wholesale and balancing markets. The minimum size of bids or conditions for prequalification to the market is decisive for the prospects of VPPs. In Germany, ***TSOs accept aggregation of DERs*** to be pre-qualified to provide balancing service. VPPs have sufficient ***freedom to determine the assets*** in their pools.

To further unlock the potential of VPP for providing flexibility to the German power system in the future, the next steps include, among others:

- ***Participation of intermittent renewable energies*** (in particular, solar PV and wind) and other ***small-scale DERs in the balancing market*** should be scaled up beyond pilots.
- Additional ***market design*** can be considered to ***facilitate small-scale DERs to offer their flexibility to network operators,*** because, currently, most local flexibility is not available to the distribution system operators (DSOs) or TSOs and, at the same time, the DER owners have little information about their impact on grid.
- ***Double economic burden*** from fees, levies and taxes will need to be ***removed*** for households to offer their home storage for flexibility.
- ***Standardized processes*** between independent aggregators, BRPs, consumers will need to be developed, including, e.g. how to settle compensation, measurement and validation baseline methodology, data exchange, and governance structure.

1 Introduction

Germany aims to achieve climate neutrality by 2045. Accelerating renewable energy expansion is a key pillar to achieve this ambitious target. In 2020, renewable energy accounted for 50.9% (or 248,82 TWh) of electricity generation in Germany, in which 37.2% (or 183.27 TWh) was generated by wind and solar photovoltaic (PV)[1]. It is projected that renewable energy generation will increase to 899 TWh in 2045, in which wind energy and PV will play a dominant role. [2] Given their intermittent character, the high penetration of wind and PV in the power system imposes significant challenges for grid operators and power markets to balance supply and demand. At the same time, decarbonisation of all end use sectors is associated with increasing electrification, which would result in substantial growth in gross electricity demand from 595 TWh in 2018 to 1,017 TWh in 2045[3] as well as increasing peak demand, despite significant energy efficiency efforts that would reduce primary energy demand by more than 50% compared to 2008. Thus, power system flexibility is key for achieving climate neutrality in Germany.[4]

The study aims to 1) offer key insights about the development of VPPs in Germany and its contribution to power system flexibility, through conducting case studies of VPP business models operated by different actors and analysing the key market regulatory framework, in which VPPs are embedded; 2) reflect on key enabling factors for VPPs in particular, for its flexibility provision, in Germany.

Virtual Power Plants (VPPs)

Virtual Power Plants (VPPs) have emerged as a promising solution here, by providing flexibility services to the grid and flexibility to the power market. It is a collection of distributed energy resources (DERs) that are centrally coordinated. The French utility company EDF estimates the energy aggregation and local flexibility market in Germany at 75 GW and expects a doubling by 2030.[5] DERs consist of small- to medium- scale resources that are connected mainly to the distribution grids or near the end users[6]. These DERs can be categorized into 1) distributed generation (dispatchable resources, e.g. CHPs or biogas plants, and variable renewable energy sources, e.g. wind and PV); 2) demand-side resources (demand response from flexible energy users), and; 3) energy storage (e.g. batteries, flywheels, power-to-X). Despite their potential of flexibility, they are often too small, scattered, and/or their power generation is too fluctuating to directly provide system service. A VPP, acting as an aggregator, will bundle these DERs into a sizable portfolio as a single resource. It monitors, forecasts, optimizes, and dispatches their generation, storage/release, or flexible consumption through a central IT system to enable them to participate in power markets and/or deliver the flexibility to system operators.

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[1] Fraunhofer ISE (2021). Energy Charts. Öffentliche Nettostromerzeugung in Deutschland in 2020. https://energy-charts.info/charts/energy_pie/chart.htm?l=de&c=DE&interval=year&year=2020.

[2] Prognos, Öko-Institut, Wuppertal-Institut (2021). Klimaneutrales Deutschland 2045. Wie Deutschland seine Klimaziele schon vor 2050 erreichen kann Zusammenfassung im Auftrag von Stiftung Klimaneutralität, Agora Energiewende und Agora Verkehrswende.

[3] Prognos, Öko-Institut, Wuppertal-Institut (2021).

[4] AEE (Agentur für Erneuerbare Energien) (2016). Metaanalyse. Flexibilität durch Kopplung von Strom, Wärme & Verkehr; Prognos, Öko-Institut, Wuppertal-Institut (2020).

[5] https://www.pv-magazine.com/2019/06/14/edf-to-acquire-energy2market/

[6] SWECO (2015). Study on the effective integration of Distributed Energy Resources for providing flexibility to the electricity system. Report to the European Commision.

2 Power markets and regulatory framework for VPPs in Germany

In Germany, the most relevant regulations for operating VPPs include the power market setup and regulations, interruptible loads regulation, grid congestion management, renewable energy regulations, regulations for aggregation, and regulations for residential DERs to provide flexibility. This section briefly presents these regulations, in particular, opportunities and challenges these regulations create for VPP business models.

2.1 Basic principles of German power system

Unbundling of the power supply system

Unbundling of the traditional, vertically integrated power supply system, i.e. unbundling of generation, transmission and distribution system operation, and supply to final customers, establishes a fundamentally positive environment for new market entrants and is thus essential for the development of most VPP business models. In Germany, unbundling is regulated by the Energy Industry Act (Energiewirtschaftsgesetz, EnWG). All energy companies with not less than 100,000 grid customers (§7 EnWG) are required to legally unbundle their grid operation business from the competitive business of generation or supply. This means, transmission system operators (TSO)[7] but also larger distribution system operators (DSO) operate independently from other electricity market players, such as generating companies, traders, suppliers. Smaller companies have to have strictly separate accounts for the competitive and the grid functions. Consequently, a large share of power is traded on the wholesale market.

Balancing

The primary goal of power system is to balance overall generation and consumption at all times. In Germany, every producer and consumer is assigned to a balancing group, which is managed by a balancing responsibility party (BRP, often an being energy supplier or also an aggregator). A balancing group may include, e.g., power generators or the entire generation and demand of an energy utility. The BRP ensures that the total amount of electricity generated and purchased in the balancing group matches consumption. The BRP must prepare an accurate forecast of its feed-in and withdrawal from the grid for each quarter hour of the following day and submit a schedule notification to the responsible TSO. The TSO is responsible for maintaining a continuous balance between electricity supply and demand across its area and performs clearing for each balancing group in its area every 15 minutes. It monitors the deviation between the forecast and actual situation of each balancing group and settles the imbalances using the balance service on the balancing market. The BRPs with deviations from the notified schedules need to bear the cost of using the balance service, i.e. the balancing energy price[8]. Alternatively, it may be cheaper for the BRPs to purchase or sell power on the intraday wholesale market to reduce the deviations before the settlement by the TSO[9].

Dispatch

In Germany, power plants determine their own operation schedule in an economically optimal way, based on their costs and anticipated prices on the power market. The producers of variable renewable energy (VRE), such as wind and solar, sells all generated power due to the lowest marginal costs of VRE and thus cheapest energy source on the merit order list. All decentralized trading among participants on the power market (i.e. day-ahead and intra-day, see Section 2.2) needs to be submitted to the TSO in the form of schedule. The outcome of trading determines the

[7] Germany has four TSOs: TransnetBW GmbH, TenneT TSO GmbH, Amprion GmbH, and 50Hertz Transmission GmbH

[8] SMARD (n.d.). Balancing energy. https://www.smard.de/page/en/wiki-article/6076/6086

[9] Ninomiya, Y., Schröder,J. and Thomas, S.(2019). Digitalization and the Energy Transition: Virtual Power Plants and Blockchain.Study for the GJETC

allocation of resources in the power system, i.e. the dispatch of supply and demand-side technologies. After the closure of power trading, the TSOs use balancing market to settle real time imbalance (see Section 2.2). In the case of grid congestion, the system operators have access to power plants to adjust electricity feed-in (Section 2.4).

2.2 Power markets and market regulations

Trading in the German electricity market exchange consists of three products based on different periods of time between purchase and actual delivery. Long-term trading takes place on the ***futures market*** and can start several years before actual delivery, based on long-term forecasts and estimation. Buyers use it to hedge against the risk of rising prices. The majority of electricity trading is short-term, carried out on the EPEX spot market. Short-term trading first takes place in the ***day-ahead*** market, where bids can be made no later than 12:00 at noon for a given hour in the following day, resulting in a more accurate forecasting on generation and consumption than the futures market. Once bids are accepted, electricity suppliers plan the activation of their power plants and pass the plan to the responsible TSOs in the form of schedules by 14:30 the day before. Forecast deviations from the day-ahead result are offset on the ***intraday market***, 15-minutes-products and 1–hour–products can be traded until 5 minutes before delivery (reduced from the previous 45 minutes). The continuous intraday bids are accepted on the order book principle, i.e. there is a separate price for each successful trade, instead of a uniform price. Cross-border intraday trading (XBID), which aims to create a single pan European cross zonal intraday market in Europe, was introduced in 2018. The XBID solution is based on a common IT system with one Shared Order Book (SOB), a Capacity Management Module (CMM) and a Shipping Module (SM).[10] The intraday market is gaining importance due to the increasing penetration of intermittent renewables, as it responds to the deviations due to the updated BRP forecasts of the load and renewable energy generation[11]. In Germany, VPPs have been active in both the day-ahead and intraday markets. Besides, the shorter lead time in the intraday market creates additional demand for rapidly controllable flexibility available at a short notice, which can be offered by VPPs from their pools.

After the closing of intraday market trading, the TSO procures the balancing service on the *balancing power market* to settle the *real-time* imbalance between supply and demand at the system level and its resulting frequency deviations. It was only until 2010 that a single balancing market was established, in which balancing service providers can offer their flexibility to all TSOs [12]. The maintenance of frequency can be achieved through the use of different types of balancing reserves: *Frequency Containment Reserve* (*FCR*, also known as primary control reserve) and *Frequency Restoration Reserve* with automatic and manual activation (*aFRR*, also known as secondary reserve, and *mFRR*, also as tertiary reserve). Their activation time ranges from 30 seconds to 15 minutes. The minimum bids for FCR is 1MW. Bids for FCR must be symmetric, i.e. bids offer the same capacity in both positive and negative directions[13]. The providers of FCR products will only be rewarded with the capacity price (for the willingness to reserve balancing capacity for a certain amount of time). In contrast, aFRR and mFRR are tendered separately for positive and negative reserves with a minimum bid size of 5 MW each. The provision of aFRR and mFRR is remunerated with a capacity price and a balancing energy price (billing for the balancing energy that is actually used, which is passed on to BRPs who cause the activation).

[10] https://www.amprion.net/Energy-Market/Congestion-Management/Multi-Regional-Coupling-(MRC)-and-Cross-Border-Intraday-(XBID)/Content-Page.html

[11] Beucker, S. Et al. (2020). WindNODE-summary report: flexibility, markets and regulation

[12] Previously, imbalance was handled independently by each of the four TSOs.

[13] Positive balancing services are provided through increase generation or reduce consumption, whereas negative balancing services are provided by decreasing generation or increasing consumption.

Table 1: Features of three balancing energy products

	FCR	aFRR	mFRR
Time to activate	30 seconds	5 minutes	15 minutes
Minimum bid size	1 MW (positive and negative)	5 MW* (positive or negative)	5 MW* (positive or negative)
Remuneration	Capacity price	Capacity price + energy price	Capacity price + energy price

** 1MW can also be submitted if only one offer is submitted per product per TSO control zone*

In Germany, VPPs are active in the balancing power market, in particular, aFRR and mFRR. A VPP aggregates different DERs in its pool for participating in balancing market, as TSOs in Germany accept pre-qualification at the aggregated pool level.

Previously, for delivering balancing energy, the provider had to participate in a capacity auction, in which VPPs aggregating flexible loads often could not participate due to forecasting challenges[14]. Since November 2020, any pre-qualified providers, regardless of their prior participation in a capacity auction, can deliver balancing energy[15].

2.3 Ordinance on Interruptible Load Agreements (AbLaV)

The Ordinance on Interruptible Load Agreements (AbLaV), which entered into force in 2013 and was amended in 2016, allows TSOs to tender their demand for interruptible loads. It was introduced to incentivise industry to provide flexibility due to the small volume of interruptible loads available on balancing market at that time. Accordingly, interruptible loads can participate either in balancing power market or in TSOs' tendering under the AbLaV. Until 2016, the AbLaV only addressed energy-intensive industry, which resulted in not more than seven contracts[16]. The amended AbLaV in 2016 attempted to increase both the number of providers and the competition by relaxing the preconditions of participation. For example, the size of minimum bids is reduced from 50MW to 5 MW. Besides, participation of DERs at the medium voltage grid and aggregation of smaller loads are allowed.

According to the AbLaV, the TSOs issue weekly tenders for 750 MW each of immediately interruptible loads (SOL) and quickly interruptible loads (SNL) through the TSOs' joint tendering platform[17]. The consumers are compensated by both availability (capacity-based) and actual activation (energy-based). Payments for availability are based on the outcome of a competitive auction and limited to max €500/MW per week and payments for activations are limited to max €400/ MWh (§4 AbLaV). During the activation, the signal is sent by the TSO either to the consumers directly or via a VPP. The amended AbLaV creates opportunities for smaller consumers, in particular, those from the service sector, as well as a business opportunity for VPPs in addition to their previous service for industrial users to market their interruptible loads.

[14] Poplavskayaa,K. and Vries,L.(2019). Distributed energy resources and the organized balancing market: A symbiosis yet? Case of three European balancing markets. Energy Policy 126: 264–276

[15] BNetzA(2019). Einführung eines Regelarbeitsmarktes. https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2019/20191008_Regelenergiemarkt.html

[16] Wohlfarth K.and Klobasa,M.(2019). Setting course for demand response in the service sector. Energy Efficiency 12:327–341

[17] https://www.regelleistung.net/ext/static/abla?lang=en The immediately interruptible loads (SOL) must be activated less than1 second (typically 350ms). Quickly interruptible loads (SNL) can be activated by TSO within 15 minutes

2.4 Grid congestion management

One core idea of the German electricity market design "Electricity Market 2.0" is the separation between power markets and grid congestion management. While the electricity wholesale market with a large price zone forms price signals, it does not fully take into account the physical transport capacity of the grid system. The management of domestic grid congestion takes place outside the market [18]. The system operators (currently the TSOs) can take a cascade of measures to eliminate grid congestion, according to the law (EnWG and EEG):

- TSOs conduct load flow analysis for the next day based on the notification submitted by BRPs. They forecast if and to what extent the dispatch on the wholesale market will negatively impact any parts of the grid. In case of grid congestion, TSOs can call on redispatch (EnWG §13 para. 1), i.e. instructing plant operators in one place to reduce their feed-in, which is originally dispatched on the wholesale market, and operators in another place to increase their output[19]. Redispatch thus forms the interface between electricity trading on the wholesale market and the physical challenges of the grid infrastructure [20]. Until now, participation is mandatory for conventional power plants with a capacity greater than 10 MW. In case that the plants are instructed to shift their feed-in, they are compensated for the incurred costs and lost revenues.
- If redispatch of conventional power plants is not sufficient, TSOs can take the emergency measure for further adjustments of electricity feed-in (i.e. feed-in management), which affects renewable electricity and CHPs (e.g. curtailment of renewables). This comes as the last option for congestion management, as renewable electricity has a feed-in priority.

From 1 October 2021, the amended Grid Expansion Acceleration Act (NABEG) will come into force, which specifies measures for reforming grid congestion management, including Redispatch 2.0. With the amendments, plants with a capacity not less than 100 kW and all DSOs will also be obliged to participate in redispatch. It means that much more capacity will be included in redispatch[21]. First, it lowers the minimum size for participating in redispatch, i.e., from 10MW to 100kW. As a consequence, a new market role, the "deployment manager", is introduced. A plant operator of a controllable resource can assign its redispatch related responsibilities to a deployment manager. The deployment manager is then responsible for the deployment of controllable resources.[22] Each controllable resource is assigned to exactly one resource manager (Az. BK6-20-059). Second, it allows TSOs and DSOs to also redispatch renewable electricity and CHP plants, still, redispatch for conventional power plants will occur first. However, the amendment does not address the potential of flexible and connectible loads from consumers. Redispatch 2.0 includes two alternative compensation models: a) forecast model, the grid operator forecasts plant operation without requiring information from the specific plant operator. The compensation for reduced feed-in will be calculated based on the forecast; b) planned value model, the plant operator – or the deployment manager – needs to transmit the planning data for compensation calculation. In both cases, for calculating the compensation, the plant operators are obliged to transmit meteorological data (for wind and PV) to the grid operators[23]. The possible participation of renewable plants, the newly introduced role of "deployment manager", and communication requirements in Redispatch 2.0 thus creates a new business opportunity for VPP operators.

2.5 Renewable energy regulations

The amended Renewable Energy Sources Act (EEG) in 2012 introduced 'direct marketing' for electricity from renewables as an optional alternative to the fixed feed-in tariff (FiT). Under 'direct marketing' as defined by the law, the renewable generators sell electricity on the wholesale

[18] Hirth, L.et al.(2019). Cost- or market-based? Future redispatch procurement in Germany

[19] Depending on how quickly a plant can provide redispatch, TSOs can request for redispatch between seven days in advance to in real time.

[20] BMWi (2019). Electricity Market:A modern electricity market. https://www.bmwi.de/Redaktion/EN/Dossier/electricity-market-of-the-future.html

[21] BMWi (2020). Bericht des Bundesministeriums für Wirtschaft und Energie nach § 63 Absatz 2a EnWG

[22] BDEW (2021). Rollenmodell für die Marktkommunikation im deutschen Energiemarkt. Arbeitsgrundlagen Marktkommunikation, at p. 11.

[23] Nextkraftwerke(n.d.) Redispatch 2.0 https://www.next-kraftwerke.de/virtuelles-kraftwerk/redispatch-2-0

market. They then receive the selling price on the market and a 'market premium' i.e. the difference between the so-called 'value to be applied' [24] and the average monthly wholesale (day-ahead) market price. The EEG amendment in 2014 made direct marketing obligatory for all new renewable electricity installations above 100kW. Furthermore, biogas installations additionally receive a capacity-oriented flexibility supplement, for example, newly installed flexible capacities receive a flexibility supplement of up to 65 EUR/kW per year (§50a EEG 2021). Consequently, medium-sized renewable power producers above 100 kW are motivated to connect to VPPs for selling power on the wholesale market. The resulted increasing number of plants connected to the VPP significantly improve the business opportunities of German VPPs and also enables the VPPs to expand their key activities, e.g. by providing to these plants the service of participating in balancing power market.

2.6 Aggregator regulations

With increasing penetration of renewable energies in the power systems, favourable regulations for VPPs have been created both at European level and in Germany. Although the concept of VPPs has not been legally defined yet, it is comparable to the legal definition of "aggregators".[25]

At the European level, the term "aggregator" was firstly legally defined in 2012 as a service provider for load management (2012/27/EU, Art. 2 No. 45). The Clean Energy for All Europeans Package in 2019 is claimed to be a real boost to aggregators. [26] In the European regulation (EU/2019/943) and directive (EU/2019/944) on common rules for the internal market for electricity, aggregation is defined more precisely[27] and the different opportunities for aggregators to participate in the energy market are outlined. Aggregators can participate in all balancing markets and provide the corresponding services (2019/943, Art. 6 & 7). Importantly, Article 17 (2019/944) also requires Member States to ensure that TSOs and DSOs, when procuring ancillary services, treat aggregators of demand response in a non-discriminatory manner.

Current regulations in Germany provide VPPs with sufficient freedom to determine the DERs in their pool, in terms of the number and types of units (renewable energy plants[28], flexible loads, storage, etc.), which allows them to provide various balancing services. In Germany, aggregators are authorized to bundle resources from several balancing groups in a single pool[29]. This enables them to substantially expand their pools and improve their business case while lowering transaction costs. They are also allowed to be active in both the wholesale market and the balancing market, as illustrated in section 2.2. On the other hand, independent VPPs, who are not affiliated to the customer's supplier[30], need to ensure that energy feed-in and withdrawals are duly notified and to obtain an explicit authorization from the BRP. This may represent a barrier for VPPs: a) BRPs may not want to risk increasing their portfolio imbalances, because aggregators' pooling of energy resources from their consumers would change their schedule and thus lead to additional imbalance costs [31];b) BRPs, often the utilities, are potential competitors for aggregation services. Another major barrier that impedes the development of independent aggregators is an overall lack of standardized processes and contracts between independent aggregators, BRPs, and consumers/prosumers, which results in high transaction costs[32].

The Federal Network Agency (BNetzA) proposed an "Aggregator-Model" in 2016 and initiated a stakeholder

[24] Since EEG 2017, new solar and wind energy plants on land with an installed capacity of 750 kW or more and biomass plants with an installed capacity of 150 kW or more have to participate in auctions. The plant operator bids on the 'value to be applied' of a plant in cents per kWh. Plant operators who were successful in an auction receive the proposed 'value to be applied' for the next 20 years ('pay-as-bid procedure').

[25] Antoni, J., et al. (2020). Netzstabilität im Stromsystem aus institutionenökonomischer und rechtlicher Perspektive – Einführung in die Problemstellung und systematischer Überblick, at p. 31.

[26] Poplavskayaa,K. and Vries,L.(2020). Aggregators today and tomorrow: from intermediaries to local orchestrators? in Sioshansi, F.(eds) Behind and Beyond the Meter Digitalization, Aggregation, Optimization, Monetization. Academic Press, at p. 106.

[27] Aggregation refers to "a function performed by a natural or legal person who combines multiple customer loads or generated electricity for sale, purchase or auction in any electricity market"

[28] Renewable energy units are mainly biomass, because participation of intermittent renewable energy, such as PV and wind, in balancing market, though not prohibited, is still in test phase (Poplavskaya and Vries,2019)

[29] Poplavskaya and Vries (2019)

[30] ' EU 2019/944

[31] Poplavskayaa,K. and Vries,L.(2020).

[32] Wohlfarth and Klobasa (2019)

process to discuss the proposal with relevant market actors. The process led to an industry guideline (BNetzA Az. BK6-17-046), including, among others, a definition of the "Aggregator" as a market role. Last but not least, in July 2021, aggregators' roles, market opportunities and obligations are legally defined in the German energy law[33].

2.7 Regulations and preconditions for residential DERs to provide flexibility

Storage as flexibility sources

In Germany, households (and consequently their flexibility resources) are classified as final customers by the Energy Industry Law (EnWG) and are thus obligated to pay when withdrawing as well as storing electricity from the grid (levies and taxes[34]) and feeding into the grid (the concession fee, grid usage fees and electricity tax). Storage that is exclusively used for storing and feeding in electricity to the grid can be exempted from taxes and grid fees[35]. Since home storage systems are usually used to optimise self-consumption, they are mostly not eligible for this exemption[36]. Such a double burden makes it unprofitable for households to offer their home storage or their battery electric vehicle for flexibility today, even if they had a smart meter.

Smart meters

Smart meters enable communication between consumers, producers, prosumers, suppliers, and a smart grid, thereby allowing for intelligent management and automation of both supply and network. Thus, smart meters are a key infrastructure to tap the households' potential for flexibility provision. In Germany, TSOs are obliged to install smart meters for end users with electricity consumption between 6000 and 100,000 kWh/year (BMWi, 2020). Due to strong data protection regulations and the need to develop safe data transmission technologies, the rollout started only in early 2020 and is aimed to be completed by 2032. Recently, the EEG (2021) obligates 1) PV plants with a capacity of more than 7 kWp to install a smart meter and to communicate how much electricity they feed into the grid; 2) PV plants with more than 25 kWp to be remotely controllable. These new rules are expected to accelerate the smart meter roll-out.

[33] On July 16, 2021 in the "Act to implement EU requirements and regulate pure hydrogen networks in energy law".

[34] They were previously also subject to renewable surcharges and are now exempted.

[35] According to EnWG and Electricity Tax Act (StromStG)

[36] Schönfisch M., et al. (2020). Aggregation von Haushalten in (regionalen) virtuellen Kraftwerken

3 VPPs in Germany: overall development and case studies

In Germany, VPPs are fully commercialized. As outlined in Chapter 2, due to the direct marketing introduced by the EEG, a first major business for VPP operators in Germany was to sell the power produced by medium-sized renewable energy plants above 100 kW in the wholesale market as required by the direct marketing, and this allowed to pool these plants to a VPP and offer to optimise the selling of their power in the day-ahead market. In addition, VPPs also facilitate energy units with high flexibility, such as biomass and hydro power plants, to profit from the intraday market and the balancing market. Nowadays, in addition to renewable energy plants, VPPs also include gas-fired CHP, battery storage, emergency generators, and demand response in their portfolio.

According to its operators, VPPs in Germany can broadly be categorized to three types:

- Independent VPP operators, which are not affiliated to the conventional customer's supplier. They can also act as supplier (currently mainly large customers above 100 kW) and thus BRP.
- Large utilities (multi-national, regional, and municipal) pooling their own generation assets and possibly their customers' loads and generation to a VPP. As utilities, they are also BRP;
- Niche actors, in particular, manufacturers of small-scale DERs, which mainly aggregate DERs of their customers to a VPP.

Table 2 illustrates examples of active VPPs in each category and their key activities. Since the prices for aFRR and mFRR service have dropped during recent years, mainly "low-hanging fruit" have been included in VPPs' offers to these services, i.e. CHP (natural gas and biogas/biomass), non-CHP biogas/biomass, and some storage facilities[37].

Table 2 Active VPP examples in Germany

Features	Next Kraftwerke	e2m	Entelios	GETEC Energie	MVV Energie	BayWa.re	Sonnen
Portfolio	Generation, demand, storage	Generation, demand, storage	Demand	Generation, demand	Generation, demand	Generation	Storage
Porfolio size	9016MW (in 2021)	3.260 MW (in 2021)	> 1 GW (in 2018)	over 3000 MW	500 MW (in 2015)	3.300 MW (in 2019)	
Asset management and optimization	x	x	x	x	x	x	x
Balancing service	x	x	x	x	x	x	x
Direct marketing	x	x	x	x	x	x	
Whitelabel solutions to utilities	x	x	x				
DR (commercial and industrial	x	x	x	x	x		x
Household DR							x
Electricity supply to consumers/prosumers					x	x	x

Independent VPP | Utility VPP | Niche VPP

Source: Compiled based on FFE 2019[38][1], Poplavskaya and de Vries (2020)

[37] ibid

[38] FFE (Forschungsgesellschaft für Energiewirtschaft mbH) (2019). Überblick über aktive Aggregatoren in Deutschland.

The following sections present selected case studies of VPPs initiated by the above-mentioned three types of operators in Germany.

3.1 VPP business model by independent aggregators

Next Kraftwerke (NEXT) was established in 2009. It is among the earliest and one of the largest European VPPs, which has aggregated 11,049 units with a networked capacity of 9,016MW[39]. They include biogas plants, CHP, hydropower, PV, battery storage, power-to-gas, EV, industrial loads for demand response. NEXT's aggregation service is enabled by their control system, using an intelligent algorithm based on a large number of data (e.g. plant operation, weather, price signals on the market, grid) to make renewable generation and industrial users more flexible and responsive to price signals. The system a) enables communication between NEXT, individual assets, the TSO, and the power exchange; b) creates individual schedules for the assets and automatically regulates them.

Their key activities related to flexibility include:

- Adjusting to the signals on intraday market

The intraday market is an essential tool to balance the overall system. NEXT adjusts the dispatchable energy generation (e.g. biogas plants) and loads in its portfolio to operate toward the varying electricity price on the market, resulting in revenue for the DER owners while contributing to system balancing. Taking the example of a biogas plant connected to NEXT, its power generation is controlled in a 15-minute interval via the Next Box and adjusted up and down as often as 20 times a day, based on current prices on the wholesale market to optimise revenue for power generation[40].

To encourage load shifting of their industrial and commercial clients, NEXT offers them different types of tariff, taking into account varying electricity price on the intraday market (the set-up of the tariff depends on, e.g. the time of use, how flexible the user can adjust their production schedule). The choice of the tariff depends on the flexibility of consumers. Consumers can decide to implement the schedules themselves according to the price signals sent by the NEXT or be fully automatically regulated by NEXT[41].

- Providing balancing service by its aggregated assets

NEXT has been active on all three balancing markets. By mid 2021, NEXT has aggregated 2,780MW of assets to provide balancing service (75 MW FCR, 983 MW aFRR, 1,762 MW mFRR)[42] . Individual asset owners generate revenues through participating in the balance market (capacity price and energy price introduced in Section 2.1). NEXT takes a share of the revenue.

- Supporting marketing interruptible loads

NEXT also supports consumers with constant load profile from the industrial and service sector in marketing their interruptible loads through providing marketing service and prequalification service.

- Help BRPs to reduce the risk of deviations within their balancing group and to avoid thus associated payment.
    - Supporting BRPs in balancing group management, e.g., quarter-hourly balancing group management, energy data management, and communication with TSO. NEXT can take over balance management completely or partly.
    - Supporting BRPs in portfolio management through first optimising generation and consumption forecasts and then settling the deviation between forecast and realised schedules in the following day through electricity trading on intraday market.
- Supporting plant operators in providing flexibility under Redispatch 2.0

Under Redispatch 2.0, various data need to be transmitted to the grid operator for forecasting and compensation calculation. NEXT will act as a deployment manager for the plant operators, which close contract with them for direct marketing, and will transmit required data to system operators.

- Software-as-service

Except for operating VPP, NEXT also offers a customizable VPP (NEMOCS) as a software solution for energy firms to build their own VPP. Besides, they provide software (NEXTRA) for utilities' balance group management.

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[39] https://www.next-kraftwerke.com/company

[40] Lehmbruck,L. et al.(2020).Aggregation of front- and behind-the-meter: the evolving VPP business model. in Sioshansi, F.(eds)Behind and Beyond the Meter Digitalization, Aggregation, Optimization, Monetization.Academic Press

[41] https://www.next-kraftwerke.de/virtuelles-kraftwerk/stromverbraucher

[42] NRW.Invest (2021). Joint Venture Toshiba ESS - Next Kraftwerke

Furthermore, the rapid growth of electric vehicles (EVs) creates new opportunities for VPPs. NEXT recently joined a research project, which aims to enable the provision of balancing services by batteries in electric automated guided vehicles (AGV) at the Hamburg shipping port. In the project, NEXT has developed concepts for the fleet's prequalification to provide control reserve as well as the charging system of the AGV that connects to VPP and trades the control reserve power. The project has also developed a prognosis algorithm enable the AGV to provide control reserve while ensuring logistical operations[43].

3.2 VPP business model by municipal, regional, and multi-national utilities

Generally speaking, German utilities are composed of five very large energy utilities "big 5"(E.ON SE, Uniper, EnBW AG, RWE AG, Vattenfall GmbH) with a number of regional DSO and supply subsidiaries and about 900 small and medium-sized municipal utilities (so-called Stadtwerke). The former are mostly multi-national companies and have dominated power generation; the latter are mostly owned by municipalities and provide local basic public service including energy supply and services. In comparison to independent VPPs with competent (Information and Communication Technology) ICT or energy management technology knowhow but no own DER assets, utilities' VPPs have their own energy assets, for example, CHP plants, which can provide high flexibility. More and more large heat storage tanks have been installed to increase the flexibility of CHP plants (decoupling power generation from feeding heat into the district heating network according to heat demand), often in combination with immersion electric heaters in order to be able to use power for heat generation when power exchange prices are very low or even negative. The CHP plants can thus be used for maximising revenue in the day-ahead market, optimization in intraday trading on the power exchange, and for providing services on the balancing market. Furthermore, as BRPs, utilities can use the flexibility of CHP plants for balancing group optimization, i.e. ramping power generation up and down to meet demand of the electricity customers in real time enabled by the heat storage. This will allow them to avoid purchasing or selling power in the intraday market or to pay for balancing energy[44]. More recently, utilities have started to explore the potential of their customer loads with VPPs in addition to generation assets. In the following, two recent examples of such VPP pilots are presented.

EON, one of the "big5", has developed a VPP, marketing the electricity and flexibility of 150 plants (600 MW) in Germany and the U.K[45]. The VPP includes power generation units (CHPs, gas and steam turbines, emergency power generators, wind power plants), energy consumers (industrial loads, pumps, power-to-heat), and storages (e.g. batteries). E.ON provides consumers with ICT devices in order to remotely manage the plants and optimize the plants' revenue as well as to enable them participating in the different balancing markets without negatively influencing their core business (e.g. in the case of industrial loads)[46]. In cooperation with thyssenkrupp, the largest flat steel producer in Germany, E.ON now includes a thyssenkrupp electrolysis plant for green hydrogen production to its VPP portfolio. The plant can increase and decrease its production quickly to provide flexibility. Through the connection to E.ON's VPP, the plant provides primary control reserve (FCR) on the balancing market[47]. Green hydrogen will support the decarbonization of energy intensive industrial processes and provide seasonal balancing in the future (Prognos et al. 2021). In case renewable energy production surpasses energy demand, large-scale electrolysis plants can use the energy to produce hydrogen. In this way, green hydrogen generation can contribute to power system stability. At the same time, the participation in the balancing market also brings additional revenue and thus enhances economic viability of green hydrogen.

The municipal utility WSW recently completed a research project of VPP development[48]. The project focused on the flexibility of private households. Smart meters were installed for 500 private households, providing them with a minute-by-minute overview of their individual

[43] Lehmbruck, et al.(2020).

[44] Ninomiya et al. (2019)

[45] E.ON (2020). E.ON and thyssenkrupp bring hydrogen production on the electricity market. https://www.eon.com/en/about-us/media/press-release/2020/2020-06-30-e-on-and-thyssenkrupp-bring-hydrogen-production-on-the-electricity-market.html.

[46] E.ON (2021). Virtuelle Kraftwerke. https://www.eon.de/de/gk/energieloesungen/energievermarktung/virtuelle-kraftwerke.html.

[47] E.ON (2020).

[48] WSW (2021). VPP Forschungsprojekt "WSW: Wuppertal spart Watt". https://www.wsw-online.de/wuppertalspartwatt/.

consumption. The households were then incentivized to shift loads to times when there is a high level of renewable energy production in the system. They received signals (red, yellow, green) on a two-hourly-basis, indicating whether the use of electricity is currently more beneficial or more problematic, and had to react manually. Three parameters were used for this assessment: day-ahead markets, local energy supply, and grid stability.[49] The five "best" consumers were awarded with free electricity supply for one year. In a third step, WSW, in cooperation with the local University, evaluated the technical and social-economical impacts of this trial. Results show that one third of the participants' load profiles were adjusted to the signals to a certain extent and load shifting of up to 23% was realized.[50] The example shows that local grid balance can be improved with comparatively simple technological means and information and incentive mechanism for consumers. However, cutting-edge ICT software and hardware are necessary to enable consumers to participate in balancing markets via VPPs.

3.3 VPP business models by niche actors

Given the potential of DERs for flexibility provision, manufacturers of these DERs, such as home battery storage, heat pumps, battery electric vehicles (BEVs), have also launched VPPs by pooling their customers' DERs.

Sonnen is a home battery provider. It initiated a community among the owners with a PV system and Sonnen battery, who can share self-produced electricity with other community members through a virtual energy pool. The members are virtually and intelligently connected to each other through a blockchain-based centralized software platform and individual smart meters. They can feed surplus electricity into the community or draw the electricity they need from it. The sonnenCommunity eventually becomes a VPP. All members who make their sonnenBatteries available to provide balancing service, i.e. short-term temporary storage, will receive free electricity up to certain amount, depending on the tariff package. In 2018, Sonnen VPP with a size of 1MW was prequalified by Germany's largest transmission system operator TenneT to participate in balancing market. The goal was to expand it into 100MW in the near future[51]. In addition, sonnen batteries had successfully implemented the Germany-wide redispatch in a project with TenneT. When there is an oversupply of wind energy and grids cannot transport it to where it is needed, the electricity will be stored in the sonnen batteries within the VPP.

In order to achieve climate neutrality by 2045, heat pumps are expected to grow significantly due to their high efficiency and decarbonisation potentials. Prognos et al. calculate that six million heat pumps will need to be installed by 2030 and 14 million by 2045.[52] While heat pumps may increase electricity consumption, it is at the same time a flexible resource. Heat pumps used in energy efficient buildings can be turned off for several hours without affecting thermal comfort. ewi ER&S estimates that heat pumps can reduce demand peaks of single households by up to 50% without compromising comfort, thus providing substantial potential for load shifting and demand peak reduction.[53] Germany's leading heating and cooling solution provider Viessmann and TenneT recently launched the ViFlex pilot, in which they will test how to utilise the potential flexibility of heat pumps for grid congestion management and to form a VPP consisting of heat pumps (with their heat storage tanks) and electricity storages. Viessmann will synchronise heat pumps of their consumers with TenneT's grid management requirements through an app they developed to maximize customers' comfort and efficiency[54].

[49] Hobert, A., et al. (2021). Analyse von Flexibilitätsoptionen in urbanen Quartieren. ew-Magazin 1/2021, pp. 18–21.

[50] Hobert, A., et al. (2021).

[51] Enkhardt,S. (2018). Sonnen to provide primary balancing power to German grid from networked home storage https://www.pv-magazine.com/2018/12/05/sonnen-to-provide-primary-balancing-power-to-german-grid-from-networked-home-storage/

[52] Prognos, Öko-Institut, Wuppertal-Institut (2021).

[53] ewi Energy Reseachr & Scenarios gGmbH (2018). Kurzstudie: Flexibilitätspotenzial von Haushalten zur netzdienlichen Reduktion von Nachfragespitzen.

[54] Tennet (2020). Viessmann and TenneT launch first project for smart use of heat and electricity https://www.tennet.eu/news/detail/viessmann-and-tennet-launch-first-project-for-smart-use-of-heat-and-electricity/

4 Conclusions

In Germany, VPPs have already contributed to power system flexibility by enabling their aggregated DERs to operate to varying electricity price on the short-term electricity exchange and to provide balancing services to TSOs on the balancing market. More recently, VPP pilots have been launched to optimise supply and demand at the medium- and low-voltage grid. Under Redispatch 2.0, VPP operators are also ready to take the role as a deployment manager to support their renewable plant operators in providing flexibility to address grid congestion.

Through providing flexibility, VPPs can thus support renewable energy expansion and increasing electrification, not to mention, the core business of VPPs in Germany is to support direct marketing of renewable energy. At the same time, flexibility provided by VPPs can potentially avoid building new peak generating capacity as well as expanding grids and thus reduce investments in power system infrastructure while bringing new revenue for owners of DERs.

In the following, the key enabling factors for VPP development and its flexibility provision in Germany are summarised.

4.1 Requirements for VPP business models

Technical requirements:

- Given the large pool of energy assets, VPP needs an ***advanced ICT software platform,*** which allows a large number of DERs to connect. The platform should be able to ***capture data*** (e.g. plant operation, meteorological data, price signals on the market, grid situation), ***enable secure and fast communication*** between VPP, individual assets, the TSO, and electricity market, and ***automatically regulate*** the DERs to participate in electricity markets and provide grid congestion service. It relies on ***advanced forecasting algorithms*** to develop an optimised dispatch schedule.
- ***Hardware***: Real-time data capture from, communication with, and controlling of DERs in the portfolio requires ***smart meters, remote control, and automation systems.***

DERs in the portfolio:

- In order to increase revenue, it is important to build a ***diverse set of DERs (demand, supply, and storage)*** and ***explore business opportunities on different markets. Biomass/ biogas power and hydropower*** plants are considered as ***indispensable resources*** for VPPs in Germany due to their high flexibility. ***Small-scale DERs,*** *such as BEVs, heat pumps, home storage*, rooftop PV, will play an increasingly important role in flexibility of the future power system. Yet their potentials have not yet been tapped due to the slow rollout of smart meters and regulatory barriers. ***Green hydrogen electrolysis plants*** can also provide short- and long-term flexibility similarly to biogas power plants. Both VPPs and grid operators in Germany have acknowledged the potential of these DERs and have launched a number of experiments, in which DERs not only participate in electricity market but also provide flexibility to address grid congestion (VPP in cooperation with TSOs) and balance at the distribution grid level (municipal utilities' own VPPs).
- Another key factor of successful VPP operation is to ***actively motivate owners of these diverse DERs*** to connect to VPPs and participate in flexibility provision, through fair and transparent economic incentives (e.g. time-dependent prices) and awareness-raising and information provision (e.g. NEXT have a large glossary to explain all key concepts related to their service).

4.2 Enabling environment for VPPs in Germany

The power market and regulatory framework in Germany have created favourable conditions for VPPs to provide flexibility services:

- The German government aims to prepare renewable power plants for the market, in particular, through the ***direct marketing obligation for medium-sized plants***. This created a key service area of VPPs in Germany. In addition, the ***unbundling*** of the vertically integrated power supply system established a fundamentally positive environment for new entrants, including independent VPPs.

- The German electricity market allows electricity trading ***close to real-time*** (***intraday market***). The shorter lead-time creates additional demand for rapidly controllable flexibility available at a short notice, which can be provided by VPPs from their pools.
- With the ***balancing group approach***, TSOs need to purchase balancing energy from the balancing market, on which VPPs can offer flexibility from the assets they aggregate. In addition, a ***single balancing market*** enables balancing service providers such as VPPs to provide balancing services to all TSOs, which increases business opportunities for VPPs.
- The roles, market opportunities and obligations of aggregators (VPPs) are ***legally defined*** in the German energy law.
- ***VPPs' access to markets***: Both European and German regulations ensure VPPs' access to wholesale and balancing markets. The minimum size of bids or conditions for prequalification to the market is decisive for the prospects of VPPs: if the minimum size is too high or prequalification is too strict or even excludes some types of DERs, this will limit the possibilities of VPPs to participate. In Germany, ***TSOs accept aggregation of DERs*** to be pre-qualified to provide balancing service. VPPs have sufficient ***freedom to determine the assets*** in their pools, in terms of numbers and types of DERs (balancing service provided by intermittent renewable energy generators, such as PV and wind, is still in its test phase). Minimum bid sizes were reduced in the past to 1 MW, but could be reduced further.

To further unlock the potential of VPP for providing flexibility to the German power system in the future, the following seems necessary:

- ***Participation of intermittent renewable energies*** (in particular, solar PV and wind) and other ***small-scale DERs in the balancing market*** should be scaled up beyond pilots.
- Additional ***market design*** can be considered to ***facilitate small-scale DERs to offer their flexibility to network operators,*** because, currently, most local flexibility is not available to the DSOs or TSOs and, at the same time, the DER owners have little information about their impact on grid. A prominent solution could be the establishment of ***regional flexibility market***, serving as an independent trading platform between DERs and DSO network operators. VPP operators will have new opportunities from this development through bundling offers from DERs in such a market than just requiring DSOs to offer reduced tariffs to flexible consumers, which is discussed as an alternative or in addition to such markets.
- ***Double economic burden*** from fees, levies and taxes will need to be ***removed*** for households to offer their home storage for flexibility.
- ***Standardized processes*** between independent aggregators, BRPs, consumers will need to be developed, including, e.g. how to settle compensation, measurement and validation baseline methodology, data exchange, and governance structure.

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