Economic Optimal Implementation of Virtual Power Plants in the German Power Market

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Abstract: The burden of excess energy from the high renewable energy sources (RES) share creates a significant reduction of residual load for the future, resulting in reduced market prices. The higher the share of stochastic RES, the more often the price will be 0 €/MWh. The power market needs new methods to solve these problems. The development of virtual power plants (VPPs) is aimed at solving techno-economic problems with an increasing share of RES in the power market. This study analyses a possible implementation of stochastic and deterministic RES in a VPP to generate secured power, which can be implemented in the European Power Exchange (EPEX)/European Energy Exchange (EEX) power market using existing market products. In this study, the optimal economic VPP configuration for an RES-based power plant is investigated and implemented into standard power market products. The results show that the optimal economic VPP configuration for different market products varies, depending on the energy availability and the marginal costs of the VPP components. The size of the VPP components is positively correlated to the components’ share of the energy generated. It was also found that projecting or implementing VPPs in Germany at current market prices (EPEX/EEX prices) is not yet economically feasible for a small share of market products. However, the secured power can be marketed on the SPOT and in the futures market with higher and more stable prices compared with the status quo.

Keywords: VPP; marketing; configuration; energy transition; power market; EPEX; EEX; power market products

1. Introduction

One of Germany’s energy transition plans involves increasing the share of renewable energy sources (RES) in total electricity consumption, in order to reduce fossil-fuel dependencies over a long term perspective. The RES share of gross electricity consumption in Germany in 2016 has reached about 31.7%, from a targeted share of 35% in 2020, and 80% in 2050 [1,2]. In 2015, Germany had a total power generation of 651.8 TWh (51.8 TWh were exported, and 30% originated from RES [3]). Until the end of 2014, the RES share was dominated by wind (77.3%), followed by solar photovoltaics (PV) energy (15.5%) and others (7.2%) [4]. The contributors of this high share of RES to the total amount of electricity generated are not only large-scale power generators, but also the owners of decentralized energy resources (DER) and small-scale RES-based power plants, such as solar PV from private owners [5].
The problem with this high share of stochastic RES in the total amount of electricity generated, and its simultaneous power generation, is the temporary surplus of power. This surplus leads to a drop of prices tending to 0 €/MWh in a free market [6]. The higher the share of stochastic RES, the more often the price will be 0 €/MWh. The power market needs new methods to solve these problems [7].

The development of virtual power plants (VPPs) aims to solve techno-economic problems regarding an increasing share of RES in the power market. The implementation of VPPs in the power market is a possibility to convert energy from stochastic power plants into secured energy by mixing it with small amounts of energy from deterministic power sources. This approach not only provides secured power [8–17], but also brings DER, including RES, to the power market, to become competitive, as compared with fossil-based energy generators [18,19]. The VPP is a part of the internet of energy (a scenario in energy transition) [20], and it is a mature technology that has already been implemented [21]. It has been shown that DER in a VPP gain more revenues than independent and non-market-oriented DER operations [22]. In the VPP, DER also have the flexibility to participate in many trading options in the power market, such as in the Day-Ahead and in the Intraday markets [23–25]. The studies from the literature [9,26] show that implementing RES in a VPP could reduce RES costs in short-term power markets, thus increasing benefits of RES.

Previous studies such as the works of [27,28] have explored the implementation of a VPP in the power market with different control schemes. Many of the studies also concern the stochastic and deterministic analysis for demand response, such as that by the authors of [29], which can help the VPP to cope uncertainties of RES. However, studies on optimal economic VPP configurations for RES-based power plants in the existing market products, especially in Germany’s power market, are still missing.

This study analyses a possible implementation of stochastic and deterministic RES in a VPP to generate secured power, which can be implemented to the EEX/EPEX power market using existing market products. In this study, the optimal economic VPP configuration for an RES-based power plant is investigated and implemented into standard power market products. The investigation on the projection of the VPP with different market products presents the idea to provide secured market products from the high RES share.

To address the issue in this study, the following steps are conducted:

- Data collection of load schemes and market prices (EEX, EPEX) for several market products (base, peak, off-peak, etc.).
- Adaptation of load data to the market products.
- Design of adapted VPP configurations, including an optimization concept and an information communication technology (ICT) concept.
- Balance of generation and load in an energy management algorithm.
- Sensitivity analyses to adapt and test the VPP components on different market products.
- Calculation of the contribution margin of the VPP in the analyzed scenarios.

This paper is organized as follows: In Section 2, materials and methods of the study are presented. In the materials part, the load profile, market prices, market products and adapted load profile to the market products are described. In the methods part, the configuration of the VPP, energy management, sensitivity analysis, and calculation of the contribution margin of the economic results are described. In Section 3, the economic optimal VPP configuration at different market products and contribution margin of the analyzed scenario results are presented. In Section 4, the results are analyzed, followed by the conclusions drawn in Section 5.

2. Materials and Methods

The VPP is yet to be defined, but has widely-accepted general concepts. With regards to previous studies [19,30–39], VPPs can be categorized into two main concepts: technical or commercial VPP. Technical VPPs (TVPPs) focus on technical operations and on the services of DER, whereas commercial VPPs (CVPPs) focus on TVPPs in markets operations. The technical operation functions include
real-time and scheduled operations, aggregations, ancillary services, forecasting functions, and DER maintenance and submissions. Both TVPPs and CVPPs have the same VPP components, which consist of generation technology, energy storage, and information and communication technology (ICT). Moreover, the targets of VPPs, with controls as well as boundaries and forecasting functions, are added as a component of the VPP [18,33,40]. The targets of VPPs in this study can be explained as being market products from the VPP.

In this study, the VPP was built from the combination of a solar PV system, a battery system, and an adapted biogas power plant. The biogas power plant used in this research is adapted from the “Controlling of Gas Production in Biogas Plants (ReBi)” concept [41] as a flexible power generator based on demand-driven biogas operation principle. According to the literature [42], the VPP delivers secured power for different load demands. The VPP components are divided in two main systems, which are the hardware and intelligent systems (Figure 1). In the hardware system, all of the hardware components of the VPP were made up. These include an applications server, a database server, a web server, local controllers, a battery system, and a biogas power plant. The solar PV power plant is not depicted in Figure 1; because in this case, the generated energy from the PV was derived from the local operator as external data. In the intelligent system, the “brain” of the VPP is built. This includes optimization tools and visualization tools within a graphical user interface (GUI).

![Figure 1. The virtual power plant (VPP) that was built during the study (adapted from the literature [42]).](image)

2.1. Material

2.1.1. Load Profile

A load profile is an important component for estimating the power markets [43], and it gives information about the load fluctuations or the load durations in the power markets over a specific period of time. In this study, there were no specific parameters to be considered when selecting which load data would be used as the load profiles in the VPP. It was assumed that the VPP needed to be capable of addressing several kinds of load conditions. The load profiles that had the maximum load data for winter and for summer were then selected, and these were used as load profiles in the VPP. Later on, if the VPP was to be applied to other load data, the VPP’s operator would be able to replace these load profile samples. The load data used in this study was derived from a local grid operator. There was a middle-size power plant in this grid, which influenced the expected standard load profile.

The following steps were conducted to generate a load profile from the load data for the VPP:

1. Visualizing the load data from a twelve-month load profile. The twelve-month load profile showed the load fluctuations over a year by representing a monthly range of load data.
The twelve-month load profile of analyzed data (Figure 2) showed an overview of load conditions over the year 2015, which fluctuated between 8 MW and 110 MW.

![Load profile](image)

**Figure 2.** A twelve-month load profile of the study as a marketable figure.

2. Selecting a month. The maximum load range occurred during the winter and the summer periods. The load in January and the load in July from (Figure 2) were selected to represent the months that had the highest load levels in winter and summer, respectively. The four-week load data for these selected months were then visualized in an hourly-interval load profile (Figure 3).

![Load profile of selected months in winter and summer](image)

**Figure 3.** The load profile of selected months in winter and summer.

3. Selecting a week load data from the selected months. There were no specific criteria in this study for selecting the weekly load data from the selected months over summer and winter (Figure 3). The second week in July and the fourth week in January were randomly selected to be analyzed in this study (Figure 4). These weekly load data over summer and winter were then used in the Week Futures (WF) market.

![Selected weekly load profiles](image)

**Figure 4.** Selected weekly load profiles over summer and over winter for the study.
4. Selecting two days from the weekly load profiles over summer and over winter as the samples of the load profiles in the Day-Ahead (DA) market in the SPOT market. As can be seen in the load profile in Figure 4, the highest loads during workdays in winter or in summer occurred on Monday, whereas the highest loads during weekends in winter or in summer occurred on Saturday. Thus, Monday and Saturday were selected to be used in the Day-Ahead market operation of the VPP (Figure 5).

![Selected daily load profiles](image)

**Figure 5.** Selected daily load profiles over summer and over winter for the study.

### 2.1.2. Market Prices Data and Market Products

The market products of the VPP totaled $9 \times 68$ products for the Day-Ahead market, and $9 \times 4$ products for the Week Futures market (Appendix A, Table A1). In the Day-Ahead market, there were 17 types of market products (Table A2), based on the time for when the load was required, such as the peak load bid for a load between 08:00 and 20:00 [44]. In the Week Futures market, the market’s products were the base load and peak load in summer or in winter. Nine (9) was a factor that represented the nine VPP configurations.

The market prices in the Day-Ahead or in the Week Futures market were constant over a specific time, for instance, the prices for peak load were constant from 08:00 to 20:00 [45]. Peak load demand occurred from Monday to Friday. A sample of the market prices for peak load in the Week Futures market can be seen in Figure 6. The complete market prices for both market types are provided by Table A3.

![The market prices of peak load in week futures market](image)

**Figure 6.** The sample of peak load prices over summer and over winter in the Week Futures market [45].

### 2.1.3. Adaptation of Load Data to Market Products

The load profiles from Figures 4 and 5 needed to be adapted to the market products. In this case, the volumes of the load demands in the Day-Ahead and the Week Futures markets were made constant for a specific period of time, referring to the literature [44]. For instance, the base load had a constant load over a 24 h period. The market prices and bid volumes of each of the market products were generated by a market mechanism where the demand and supply met. Equations (1) to (8) were considered based on the literature [46].
The bid volumes of the specific market products \( x \) in this study were then determined by Equation (1):

\[
BVOL_x = \sum_{k=1}^{n} c_{x,k} \left( \frac{\sum_{k=1}^{n} (g_{x,k} \cdot Pres_{l,k})}{s_x} \right)
\]  

The base load calculation was made as in Equation (2):

\[
P_{\text{base},l,k} = P_{\text{avg},l,k} - Paravg_{l,k}
\]  

If a total load of the market category \( l \) was subtracted by the base load of the market category \( l \), then there would be remaining load demands that were part of the total load, but not the part of the base load. In order to know whether there were any remaining load demands, Equation (3) was conducted:

\[
Pres_{l,k} = P_{\text{tot},l,k} - P_{\text{base},l,k}
\]  

This remaining load signal was then calculated using Equations (4) and (5):

\[
g_{x,k} = 1 \text{ (when } Pres_{l,k} > 0) \tag{4}
g_{x,k} = 0 \text{ (when } Pres_{l,k} < 0) \tag{5}
\]

The number of remaining load demands’ signals for the market product \( x \) were then calculated by Equation (6):

\[
s_x = \sum_{k=1}^{n} g_{x,k}
\]  

In order to simplify the process calculation and to reduce the processing time in the VPP in the Week Futures markets, Equation (7) for winter and Equation (8) for summer were then used to calculate the peak load in the Week Futures markets:

\[
P_{\text{peak}_w} = 2 \cdot Paravg_{w5,k} \tag{7}
P_{\text{peak}_s} = 2 \cdot Paravg_{s6,k} \tag{8}
\]

The samples of these bid calculations for the Day-Ahead and Week Futures markets are depicted in Figures 7a–d and 8a,b. The other bid type volumes are not depicted in the figures, but they are explained in Table A4.
2.2. Methods

2.2.1. The Configuration of the VPP

The VPP was configured using two main methods: the optimization algorithm and the method for the ICT configuration of the VPP. The optimization concept was built as in the literature [42] to optimize the utilization of every single component in the VPP, such as a local controller in the biogas power plant. In the end, there would be a collection of entities in the VPP, which would collaborate with each other to meet common targets, that is, to address load demands. Energy and information exchanges are conducted by these entities in the exchange lines during the operation of the VPP (Figure 9).

The ICT components of the VPP were built as in the literature [47], based on the openness of the VPP components for future ICT developments. The ICT components of the VPP included the use of state-of-the-art advanced ICT security technology (virtual private network (VPN)), cloud computing, and exchange protocols (open platform communications (OPC), transmission control protocol-internet

### Table

| Week Type | Load Demand (MW) | Time (Hours) |
|-----------|------------------|--------------|
| Winter Monday | Base load | 0 4 8 12 16 20 |
|           | Peak load | 0 4 8 12 16 20 |
|           | Total load | 0 4 8 12 16 20 |
| Summer Monday | Base load | 0 4 8 12 16 20 |
|           | Peak load | 0 4 8 12 16 20 |
|           | Total load | 0 4 8 12 16 20 |

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**Figure 7.** Adapted daily load profile of the base and peak loads for the samples of the Day-Ahead market on: (a) Winter Monday; (b) Winter Saturday; (c) Summer Monday; (d) Summer Saturday.

**Figure 8.** Adapted weekly load profiles of base and peak loads for the Week Futures market: (a) Winter Monday; (b) Winter Saturday; (c) Summer Monday; (d) Summer Saturday.
protocol (TCP-IP)). The main backbone of the ICT concepts for the VPP was the intensive use of open-source software based on community-based developments.

![Figure 9. The configuration concept for the VPP (as given [42]).](image)

### 2.2.2. Energy Management

The energy management of the VPP was based on an energy management plan as given in the literature [42], and an added component at the end of the energy exchange phase. The added component was a comparator that was intended to minimize the gap between the planned and the measured exchanged energies in the VPP. The merit order calculation was used as a strategy to aggregate the energy from the integrated energy sources (IES) [48]. The complete calculation of the IES cost and optimization was previously calculated in the literature [42]. To maintain security for the supply, with reduced generation costs in the VPP, the following considerations were taken into account for this VPP (Figure 10), as given in the literature [42]:

(a) The highest priority to meet the load demand was given to the power plants with the lowest marginal costs. Assuming that the sorted power plants, as based on marginal costs from the lowest to the highest, were the solar PV, the battery energy storage system (BESS), and the flexible biogas, the solar PV thus had the highest priority to meet the load. If the solar PV did not generate enough energy to meet the load, then the energy from the flexible biogas would be combined with the energy from the BESS (if applicable). If the solar PV generated more energy than the load, then the surplus energy from the solar PV would be stored into the BESS (in the case that state-of-charge (SOC) <100%, otherwise there would be nothing to do).

(b) As a result of biological constraints such as digestion time, the flexible biogas may need more time to aggregate its energy than the BESS. Thus, a BESS is still needed to support the flexible biogas in the operation of the VPP. If more/different intermittent RES were installed, that is, wind turbine power plants, the contribution of the BESS in the load could be minimized.

(c) The energy exchange was calculated at time t1, and then it was optimized again at time t2. Time t1 is the time when the aggregator or the operator makes the dispatch schedule for the Day-Ahead or Week Futures markets, such as on the day before the required delivery time for the energy. Time t2 is the minimum time required to compensate the gap between the scheduled and the measured exchanged energies. The balance of generation and load in an energy management system at time t2 is conducted by a comparator algorithm. Future investigation of time t2 should be conducted in practical implementation. In this study, t2 was determined to be about 2 ms with reference to the measured exchange rate in the literature [47].

In contrast to previous studies [49–52], the priority of the VPP implementation in this study was to provide secure power supply. It was assumed that all of the power plants of the VPP were participants in the energy market. However, the mechanism for selling surplus energy to the grid in this study was not economically considered, but it was instead considered as an energy surplus.
The energy exchange was calculated at time $t_1$, and then it was optimized again at time $t_2$. Time $t_1$ is the time when the aggregator or the operator makes the dispatch schedule for the Day-Ahead or Week Futures markets, such as on the day before the required delivery time for the energy. Time $t_2$ is the minimum time required to compensate the gap between the scheduled and the measured exchanged energies. The balance of generation and load in an energy management system at time $t_2$ is conducted by a comparator algorithm. Future investigation of time $t_2$ should be conducted in practical implementation. In this study, $t_2$ was determined to be about 2 ms with reference to the measured exchange rate in the literature [47].

Figure 10. The energy management system (EMS) algorithm of VPP (as in the literature [42]) with a comparator algorithm.

### 2.2.3. Sensitivity Analyses

A sensitivity analysis was conducted by adoption and testing of the VPP components from different market products. The previous composition of the solar PV, the BESS, and the flexible biogas (Table 1, refer to Table 2 configuration 1) was scaled up and it was compared with other compositions such that at the end, there were nine configurations that were used for sensitivity analyses (Table 2). It was assumed that marginal costs of PV were 0 €/kWh, the BESS marginal cost varied (depending on market prices associated with the scenario +10% losses), and the biogas marginal cost was 15 cents €/kWh based on calculation derived from previous studies [53–58]. The optimal economic VPP configuration for different market products was analyzed by evaluating the optimal economic contributions of the VPP components, based on these nine VPP configurations.

#### Table 1. Parameters of the case study for the operations of the Day-Ahead and Week Futures markets.

| Indicators        | Capacity          |
|-------------------|-------------------|
| Solar PV (MW)     | 15                |
| Biogas (MW)       | 15 or 25 $^1$     |
| Battery (MWh)     | 7.5               |

$^1$ for baseload and Week Futures.

#### Table 2. The composition of solar PV, BESS, and flexible biogas (BIO) (PV/BESS/BIO) for sensitivity analysis.

| Configuration | Composition of PV/BESS/BIO          |
|---------------|------------------------------------|
| 1             | 1:1:1 (15:7.5:15 or 25 $^1$)       |
| 2             | 1:2:1                              |
| 3             | 1:3:1                              |
| 4             | 2:1:1                              |
| 5             | 2:2:1                              |
| 6             | 2:3:1                              |
| 7             | 3:1:1                              |
| 8             | 3:2:1                              |
| 9             | 3:3:1                              |

$^1$ for baseload and Week Futures.
2.2.4. Calculation of the Contribution Margin of the Economic Results

To calculate the profits or losses of the economic results from energy management of the VPP, the cost analysis was performed by adopting the method conducted by the authors of [59]. The marginal costs and the market prices were compared in order to reveal the contribution margin of the VPP. The analysis based on marginal cost was aligned with one of the core features that was proposed by EPEX SPOT and EEX in further developments of the “erneubare energien gesetz” (EEG) [60]. The contribution margins were then calculated based on Equation (9) to 9 VPP configurations (Table 2):

\[
CM_i = MP_i - Copt_i
\]  

(9)

3. Results

When the 9 configurations of a total of 68 VPP products for the Day-Ahead market, and 4 products for the Week Futures market, were applied to energy management systems and Equation (9), the economic optimal VPP configuration and contribution margin of the different load schemes were quite different.

As an observation of VPP implementation in different load schemes, it was apparent that the share of the VPP’s components in an optimal economic VPP configuration varied over weekday/weekend times, seasonal times, VPP component sizes, and the type of markets presented (Figure 11). As expected, the sizes of the VPP components had an influence on the share of power generated by the VPP components in economic and optimal VPP configurations. In the analyzed load schemes, VPP size enlargement had a positive correlation with the share of electricity from the VPP components that had minimum marginal costs. On the weekend, compared with the weekdays, the VPP required more energy from biogas. In the Week Futures market, the share of PV was not as high as it was in the Day-Ahead markets.

In the Day-Ahead market in winter, the VPP used more than 72% of its total energy from biogas in Configuration 1 (Figure 11a). When the sizes of PV and BESS were increased, the share of biogas in the VPP could be reduced to 53% in Configuration 9 on Monday. The increasing size of PV from Configuration 1 to 9 allowed the PV to increase its share in the energy generation of the VPP up to 41.5% on Monday in Configuration 9. The BESS has the smallest contribution to the total energy used in the VPP, with a maximum of 8% share on Monday in Configuration 3. Increasing the BESS size by Factor 3 caused an increase in the BESS share in the VPP’s energy output of almost three-fold.

In the Day-Ahead market in summer, 60% of the total energy of the VPP was generated by PV. The maximum PV share in the VPP was about 80% in Configurations 7, 8, and 9 on Monday (Figure 11b). The rest of the share of the VPP was generated by biogas and BESS. The maximum biogas share in the VPP was a quarter of the total in Configuration 1 on Monday. This share decreased when the sizes of PV and BESS were increased. The use of BESS in the Day-Ahead market and in the Week Futures market in winter was relatively low (up to 10% in Configuration 3). Increasing the BESS size by a factor of 3 caused the BESS to take up an increased share of the VPP’s power generation by almost the same factor.

In the Week Futures market, the optimal VPP configuration differed between winter and summer (Figure 11c). In winter (Configuration 1), almost 90% of the energy used originated from biogas. The increasing share of PV reduced the share of biogas to 66.5%, in Configurations 7 to 9. The rest of the energy generated by the VPP came from PV. The share by BESS was not visible. In summer, the optimal VPP configuration was inverse compared to the winter scheme. The PV share was up to four-fifths of the total generated energy (in Configurations 7, 8, and 9), followed by biogas, which was up to a fifth of the total share. The contribution of BESS to the VPP in summer in Configuration 3 was less than 5%.

Additionally, the trend of the VPP’s average marginal costs for the different market products compared with the average market prices in the Day-Ahead and Week Futures markets can be seen in Figure 12. When the nine VPP configurations were applied to different market products (see Table A1) at Summer and Winter for Day-Ahead (on Monday and on Saturday) markets and Week Futures
markets, the trends of the VPP’s average marginal costs for both Day-Ahead and Week Futures markets were quite similar. The VPP’s average marginal costs were reduced when the installed capacity of the VPP components increased. These costs were lower in summer than in winter. At some points such as in the Day-Ahead and Week Futures market in summer, the VPP’s average marginal costs were lower than the average market prices.

![Graphs showing average percent share of VPP's components and average percent share of Solar PV, BESS, and Biogas in the VPP in Winter and Summer in the Week Futures market](image1)

**Figure 11.** The share of PV, BESS, and biogas in the VPP for the different market products: (a) averages on Monday and Saturday in winter in the Day-Ahead (DA) market; (b) averages on Monday and Saturday in summer in the DA market; (c) in summer and winter in the Week Futures market.

The VPP's avg. marginal costs relative to the avg. market prices

![Graph showing the VPP's marginal costs relative to the average market prices](image2)

**Figure 12.** The average VPP’s marginal costs as compared to the average market prices for different market products.
The difference between the average market price and the VPP’s average marginal cost was considered in terms of the average contribution margin (CM) of the VPP (Figure 13). The VPP earned a positive CM when it was implemented in the Day-Ahead market in summer. The maximum CM of the VPP was up to 14 €/MWh. For all other products and factors, such as during winter in the Day-Ahead and in the Week Futures markets, the CM was negative. The minimum CM in winter occurred in the Week Futures market, with an amount of up to −105 €/MWh, followed by the Day-Ahead market on Saturday in winter (up to −95 €/MWh), the Day-Ahead market on Monday in winter (up to −70 €/MWh), and the Week Futures market in summer (up to −25 €/MWh).

4. Discussion

The variations of economic optimal VPP configurations depend on the available energy and the VPP components’ marginal costs. In summer, the solar PV contributed more energy to load demands than in winter. The share of the BESS to the load demand was limited by the amount of its stored energy. In this study, the BESS was only charged by the solar PV. When the energy from solar PV to charge the BESS was low, the stored energy in BESS was also relatively low. The other parameter that influenced the share of the BESS on the load demand was the remaining energy from the previous time-step discharged processes. The BESS will not have so much available energy when the energy from the PV is minimal and the discharged energy is maximal. The biogas had the highest possibility of having the highest share of the load demand because it had the highest power generation capability. Biogas could provide a more flexible and more reliable energy source compared with the other two VPP components. However, as the marginal cost of biogas was higher than the marginal costs of PV, there was still a possibility for reducing the VPP’s average marginal costs by reducing the biogas share in addressing load demands. The introduction of another low marginal cost with intermittent RES, such as a wind turbine power plant, could minimize the average VPP’s marginal cost.

The economic optimization of the VPP components shows that as much energy as possible should be generated by intermediate power plants, as long as the security of power supply is not harmed. In some instances, comparatively large shares of variable capacities (e.g., biogas) are necessary to secure the power supply, but in this case, the share of energy from intermediate resources is still quite large.

In this study, only intermediate power from PV systems was regarded. If wind power systems were to be additionally taken into account, higher shares of intermediate RES would be the result. The simultaneity effect would be smoothed. As a result, secured power from VPP based on RES could be offered with a higher energy share of cheap, intermediate RES, leading to lower generation costs.
The results (Figure 12) revealed that the current market prices (EPEX and EEX prices) were lower than the VPP’s average marginal costs for most market types and products. One of the reasons was the comparatively low price for electricity in the EEX and EPEX market. This was caused by offers from relatively low-cost energy that was generated from non-renewable energy sources, as well as a surplus of power supply in the market, which reduced the price.

As configuration 9 integrates the most power from PV with marginal costs of 0 €/MWh, it could be preferably selected for VPP applications. This result could be transferred to other capacities with a marginal cost value of zero, as wind or run-of-river power stations. However, the energy surplus is one of the questions that the VPP operator should answer. Will the energy surplus be sold, or will it be throttled? Should more or less energy surplus be generated? In this study, the main consideration for determining IES size is a reduction of energy surplus, which is assumed to be related to low energy losses. On the other hand, it is also possible to generate surplus energy, if this energy surplus can be considered as additional revenue for the VPP. There must be further analyses made in order to reveal the actual prices of surplus energy. On the other hand, power from the VPP was generated at marginal costs of 20–80 €/MWh (summer–winter, best configuration), which were comparatively low prices for secured power from RES, but too much for an economically successful participation of the VPP in the EPEX market. Only when the share of energy from PV from the total power generated exceeded a certain level—such as in the Day-Ahead market in summer—would the VPP’s marginal costs be lower than the market prices. From the results section, it can be seen that the solar–biogas-battery VPP is able to provide secured power at all times of the year. This secured power can be marketed on the SPOT, and in the Futures market at current prices. Especially in summer, the resulting contribution margin of power from the VPP is positive or close to the break-even point.

As a result, the implementation of a VPP to answer standardized load schemes of market products (base, peak, SPOT products) changes the fluctuating feed-in from RES into a secured and predictable power supply. This will lead to more stable prices in the energy market, and less grid control.

Moreover, economic optimization is based on the maximization of the contribution margin; this is in accordance with the standard marketing of electric power in SPOT and future exchanges. The results show that the contribution margin (Figure 13) is comparable to the contribution margin of gas power plants in the EPEX market. Regarding a cut in oversupply of power in the close future, both types of power plants could become economically successful (again).

Finally, the following can be concluded from the analyzed data:

- The energy availability and the marginal costs of the VPP’s components influence decisions on economic optimal VPP configurations for different market products. In this study, it was found that biogas, as a flexible energy resource, followed by solar PV and BESS in the VPP, takes up most of the time in covering load demand as compared with other dependent RES. With the help of an energy management algorithm, the configuration of RES in the VPP will change automatically to their economic optimal compositions.
- Additionally, the size of the VPP components was positively correlated to the components’ share of the energy generated. For an economic optimization, it is thus necessary to maximize the share of cheap stochastic power sources and reduce the amount of expensive deterministic sources. Such can be done by limiting the power of wind and solar power plants in relation to the deterministic sources, so that less power peaks have to be integrated in the power band.
- The organization of RES in VPPs leads to the generation of secured power generation instead of fluctuating power generation. This secured power could be sold in the Futures market at higher and more stable prices compared with the status quo.

5. Conclusions

The paper presents the capability of VPPs to provide secured power market products based on EEX/EPEX standards. A local grid load profile was used to be answered with these market products. Analyses—including sensitivity analyses—of several VPP configurations and the resulting costs were
investigated to reveal the contribution margin of the VPP for different market types (Day-Ahead and Week Futures).

There were two main points found during this study, which are as follows:

- for all 9 VPP-configurations in the Day-Ahead and futures market, there were different figures in the economic optimal VPP configuration and contribution margin of the different load schemes. It was not only determined how the VPP manages its resources, but also how the other factors influenced the VPP’s behavior. For instance, the economic optimal configuration of the VPP components (components and size) depends on season, the kind of power plants, and the load profile. As “season” is an external variable that cannot be influenced, and the decision for the VPP components cannot be changed when undertaken, the selection of the marketing channels allows the greatest chance to maximize the contribution margin.

- The organization of RES in the VPP leads to the generation of secured instead of fluctuating power generation. This secured power could be sold in the futures market at higher and more stable prices compared with the status quo. From this, the average contribution margin of power from RES will increase, and less financial support will be necessary to cover the full costs of RES. By delivering secured power, RES will become competitive against conventional power plants, so that competitive market measures could be used to generate funds (e.g., capacity credits and measurements according to §39j EEG “innovation tender”), which will cause less turbulence in the market compared with the present priority purchase methods that are being used for RES power.

Additionally, in the future, it is recommended to investigate the impact of implementing various RES-based power plant technologies in the different locations with more parameters to be analyzed, such as weather forecast, to the decision support for long term development of VPP in the German power markets.

**Author Contributions:** D.I.C. developed the main idea of the current study, performed and interpreted the analysis, and wrote the manuscript. K.H. developed the idea of generating secured power from RES and markets it as a power future. M.N. reviewed the paper, providing general supervision and guidance. All authors have read and approved the final manuscript.

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**Nomenclature**

**Abbreviations**

| Abbreviation | Description                  |
|--------------|------------------------------|
| MWMN         | Monday Winter Middle-Night   |
| MWEM         | Monday Winter Early Morning  |
| MWLM         | Monday Winter Late Morning   |
| MWEA         | Monday Winter Early Afternoon|
| MWRH         | Monday Winter Rush-Hour      |
| MWOP2        | Monday Winter Off-Peak 2     |
| MWBL         | Monday Winter Baseload       |
| MWPL         | Monday Winter Peakload       |
| MWN          | Monday Winter Night          |
| MWOP1        | Monday Winter Off-Peak 1     |
| MWB          | Monday Winter Business       |
| MWOP         | Monday Winter Off-Peak       |
| MWM          | Monday Winter Morning        |
| MWHN         | Monday Winter High Noon      |
| MWA          | Monday Winter Afternoon      |
| MWE          | Monday Winter Evening        |
MWSP  Monday Winter Sun Peak
MSMN  Monday Summer Middle-Night
MSEM  Monday Summer Early Morning
MSLM  Monday Summer Late Morning
MSEA  Monday Summer Early Afternoon
MSRH  Monday Summer Rush-Hour
MSOP2 Monday Summer Off-Peak 2
MSBL  Monday Summer Baseload
MSPL  Monday Summer Peakload
MSN   Monday Summer Night
MSOP1 Monday Summer Off-Peak 1
MSB   Monday Summer Business
MSOP  Monday Summer Off-Peak
MSM   Monday Summer Morning
MSHN  Monday Summer High Noon
MSA   Monday Summer Afternoon
MSE   Monday Summer Evening
MSSP  Monday Summer Sun Peak
WF_SBL Week Futures Summer Baseload
WF_SPL Week Futures Summer Peakload
MWF_WBL Monday Week Futures Winter Baseload
TWF_WBL Tuesday Week Futures Winter Baseload
WWF_WBL Wednesday Week Futures Winter Baseload
ThWF_WBL Thursday Week Futures Winter Baseload
FWF_WBL Friday Week Futures Winter Baseload
SWF_WBL Saturday Week Futures Winter Baseload
SuWF_WBL Sunday Week Futures Winter Baseload
MWF_WPL Monday Week Futures Winter Peakload
TWF_WPL Tuesday Week Futures Winter Peakload
WWF_WPL Wednesday Week Futures Winter Peakload
ThWF_WPL Thursday Week Futures Winter Peakload
FWF_WPL Friday Week Futures Winter Peakload
PL   Peak Load
BL   Base Load
EA   Early Afternoon
B    Business
HN   High-Noon
SP   Sun Peak
MW   Monday Winter
SWMN Saturday Winter Middle-Night
SWEM Saturday Winter Early Morning
SWLM Saturday Winter Late Morning
SWEA Saturday Winter Early Afternoon
SWRH Saturday Winter Rush-Hour
SWOP2 Saturday Winter Off-Peak 2
SWBL Saturday Winter Baseload
SWPL Saturday Winter Peakload
SWN Saturday Winter Night
SWOP1 Saturday Winter Off-Peak 1
SWB  Saturday Winter Business
SWOP Saturday Winter Off-Peak
SWM  Saturday Winter Morning
SWHN Saturday Winter High Noon
SWA  Saturday Winter Afternoon
SWE  Saturday Winter Evening
SWSP Saturday Winter Sun Peak
SSMN Saturday Summer Middle-Night
SEEM Saturday Summer Early Morning
SLLM Saturday Summer Late Morning
SSEA Saturday Summer Early Afternoon
SSRH Saturday Summer Rush-Hour
SSOP2 Saturday Summer Off-Peak 2
SSBL Saturday Summer Baseload
SSPL Saturday Summer Peakload
SSN Saturday Summer Night
SSOP1 Saturday Summer Off-Peak 1
SSB Saturday Summer Business
SSOP Saturday Summer Off-Peak
SSM Saturday Summer Morning
SSHN Saturday Summer High Noon
SSA Saturday Summer Afternoon
SSE Saturday Summer Evening
SSSP Saturday Summer Sun Peak
WF_WBL Week Futures Winter Baseload
WF_WPL Week Futures Winter Peakload
MWF_SBL Monday Week Futures Summer Baseload
TWF_SBL Tuesday Week Futures Summer Baseload
WWF_SBL Wednesday Week Futures Summer Baseload
ThWF_SBL Thursday Week Futures Summer Baseload
FWF_SBL Friday Week Futures Summer Baseload
WF_SBL Saturday Week Futures Summer Baseload
SuWF_SBL Sunday Week Futures Summer Baseload
MWF_SPL Monday Week Futures Summer Peakload
TWF_SPL Tuesday Week Futures Summer Peakload
WWF_SPL Wednesday Week Futures Summer Peakload
ThWF_SPL Thursday Week Futures Summer Peakload
FWF_SPL Friday Week Futures Summer Peakload
LM Late Morning
M Morning
RH Rush-Hour
DA Day-Ahead market
WF Week Futures market
SW Saturday Winter
SS Saturday Summer

Variables

BVOL_x bid volumes of specific market products x
x the market products (see Table A1) such as base load, peak load, off-peak
Ptot_l,k a total load of the market category l at time k
Pbase_l,k abase load of the market category l at time k
Favg_l,k avg. of load data of the market category l at time k
Paravg_l,k avg. deviation of load data of the market category l at time k
Ppeakw the peak load market product in winter in the Week Futures market
Ppeakw the peak load market product in summer in the Week Futures market
Paravg_wavg. of load data of Week Futures in winter at time k
Paravg_savg. of load data of Week Futures in summer at time k
Pres_l,k the remaining load of the market category l at time k
s_x the number of the signal of the remaining load of the market product x
CM_l the average of contribution margin of the market category l at time k
Copt_l the average of the optimized cost of the market category l at time k
MP_l the average of the market prices of market category l at time k
l the market categories (Table A5)
**Constants**

\[ c_{x,k} = \begin{cases} 
1 & \text{if } k \text{ is equal to the times where the specific market product } x \text{ occurs (see Block Times (h) in Table A2), otherwise 0} \\
0 & \text{otherwise}
\end{cases} \]

\[ g_{x,k} = \begin{cases} 
1 & \text{is the signal of the remaining load existence in the specific market product } x \text{ at time } k \text{ when the remaining load is bigger than zero, otherwise 0} \\
0 & \text{otherwise}
\end{cases} \]

\( k \) time 1 to \( n \)

\( n = 24 \) (for Day-Ahead market) or 168 (for Week Futures market)

**Appendix A**

**Table A1.** All market products of each VPP configuration.

| Scenario | Market Types          | Bid Types       | Season | Day(s)          | Date(s)       | x   |
|----------|-----------------------|-----------------|--------|-----------------|---------------|-----|
| 1        | Day-Ahead (SPOT market) | Middle-Night Block | Winter | Monday          | 26 January 2015 | 1   |
| 2        | Day-Ahead (SPOT market) | Early Morning Block | Winter | Monday          | 26 January 2015 | 2   |
| 3        | Day-Ahead (SPOT market) | Late morning Block | Winter | Monday          | 26 January 2015 | 3   |
| 4        | Day-Ahead (SPOT market) | Early Afternoon Block | Winter | Monday          | 26 January 2015 | 4   |
| 5        | Day-Ahead (SPOT market) | Rush Hour Block | Winter | Monday          | 26 January 2015 | 5   |
| 6        | Day-Ahead (SPOT market) | Off-Peak 2 Block | Winter | Monday          | 26 January 2015 | 6   |
| 7        | Day-Ahead (SPOT market) | Baseload Block | Winter | Monday          | 26 January 2015 | 7   |
| 8        | Day-Ahead (SPOT market) | Peakload Block | Winter | Monday          | 26 January 2015 | 8   |
| 9        | Day-Ahead (SPOT market) | Night Block | Winter | Monday          | 26 January 2015 | 9   |
| 10       | Day-Ahead (SPOT market) | Off-Peak 1 Block | Winter | Monday          | 26 January 2015 | 10  |
| 11       | Day-Ahead (SPOT market) | Business Block | Winter | Monday          | 26 January 2015 | 11  |
| 12       | Day-Ahead (SPOT market) | Off-Peak Block | Winter | Monday          | 26 January 2015 | 12  |
| 13       | Day-Ahead (SPOT market) | Morning Block | Winter | Monday          | 26 January 2015 | 13  |
| 14       | Day-Ahead (SPOT market) | High Noon Block | Winter | Monday          | 26 January 2015 | 14  |
| 15       | Day-Ahead (SPOT market) | Afternoon Block | Winter | Monday          | 26 January 2015 | 15  |
| 16       | Day-Ahead (SPOT market) | Evening Block | Winter | Monday          | 26 January 2015 | 16  |
| 17       | Day-Ahead (SPOT market) | Sun Peak Block | Winter | Monday          | 26 January 2015 | 17  |
| 18       | Day-Ahead (SPOT market) | Middle-Night Block | Winter | Saturday       | 31 January 2015 | 18  |
| 19       | Day-Ahead (SPOT market) | Early Morning Block | Winter | Saturday       | 31 January 2015 | 19  |
| 20       | Day-Ahead (SPOT market) | Late morning Block | Winter | Saturday       | 31 January 2015 | 20  |
| 21       | Day-Ahead (SPOT market) | Early Afternoon Block | Winter | Saturday       | 31 January 2015 | 21  |
| 22       | Day-Ahead (SPOT market) | Rush Hour Block | Winter | Saturday       | 31 January 2015 | 22  |
| 23       | Day-Ahead (SPOT market) | Off-Peak 2 Block | Winter | Saturday       | 31 January 2015 | 23  |
| 24       | Day-Ahead (SPOT market) | Baseload Block | Winter | Saturday       | 31 January 2015 | 24  |
| 25       | Day-Ahead (SPOT market) | Peakload Block | Winter | Saturday       | 31 January 2015 | 25  |
| 26       | Day-Ahead (SPOT market) | Night Block | Winter | Saturday       | 31 January 2015 | 26  |
| 27       | Day-Ahead (SPOT market) | Off-Peak 1 Block | Winter | Saturday       | 31 January 2015 | 27  |
| 28       | Day-Ahead (SPOT market) | Business Block | Winter | Saturday       | 31 January 2015 | 28  |
| 29       | Day-Ahead (SPOT market) | Off-Peak Block | Winter | Saturday       | 31 January 2015 | 29  |
| 30       | Day-Ahead (SPOT market) | Morning Block | Winter | Saturday       | 31 January 2015 | 30  |
| 31       | Day-Ahead (SPOT market) | High Noon Block | Winter | Saturday       | 31 January 2015 | 31  |
| 32       | Day-Ahead (SPOT market) | Afternoon Block | Winter | Saturday       | 31 January 2015 | 32  |
| 33       | Day-Ahead (SPOT market) | Evening Block | Winter | Saturday       | 31 January 2015 | 33  |
| 34       | Day-Ahead (SPOT market) | Sun Peak Block | Winter | Saturday       | 31 January 2015 | 34  |
| 35       | Day-Ahead (SPOT market) | Middle-Night Block | Summer | Monday          | 6 July 2015    | 35  |
Table A1. Cont.

| Scenario | Market Types         | Bid Types         | Season      | Day(s)     | Date(s)       | x   |
|----------|----------------------|-------------------|-------------|------------|---------------|-----|
| 36       | Day-Ahead (SPOT market) | Early Morning Block | Summer      | Monday     | 6 July 2015   | 36  |
| 37       | Day-Ahead (SPOT market) | Late morning Block | Summer      | Monday     | 6 July 2015   | 37  |
| 38       | Day-Ahead (SPOT market) | Early Afternoon Block | Summer    | Monday     | 6 July 2015   | 38  |
| 39       | Day-Ahead (SPOT market) | Rush Hour Block    | Summer      | Monday     | 6 July 2015   | 39  |
| 40       | Day-Ahead (SPOT market) | Off-Peak 2 Block  | Summer      | Monday     | 6 July 2015   | 40  |
| 41       | Day-Ahead (SPOT market) | Baseload Block     | Summer      | Monday     | 6 July 2015   | 41  |
| 42       | Day-Ahead (SPOT market) | Peakload Block     | Summer      | Monday     | 6 July 2015   | 42  |
| 43       | Day-Ahead (SPOT market) | Night Block        | Summer      | Monday     | 6 July 2015   | 43  |
| 44       | Day-Ahead (SPOT market) | Off-Peak 1 Block  | Summer      | Monday     | 6 July 2015   | 44  |
| 45       | Day-Ahead (SPOT market) | Business Block     | Summer      | Monday     | 6 July 2015   | 45  |
| 46       | Day-Ahead (SPOT market) | Off-Peak Block     | Summer      | Monday     | 6 July 2015   | 46  |
| 47       | Day-Ahead (SPOT market) | Morning Block      | Summer      | Monday     | 6 July 2015   | 47  |
| 48       | Day-Ahead (SPOT market) | High Noon Block    | Summer      | Monday     | 6 July 2015   | 48  |
| 49       | Day-Ahead (SPOT market) | Afternoon Block    | Summer      | Monday     | 6 July 2015   | 49  |
| 50       | Day-Ahead (SPOT market) | Evening Block      | Summer      | Monday     | 6 July 2015   | 50  |
| 51       | Day-Ahead (SPOT market) | Sun Peak Block     | Summer      | Monday     | 6 July 2015   | 51  |
| 52       | Day-Ahead (SPOT market) | Middle-Night Block | Summer      | Saturday   | 11 July 2015  | 52  |
| 53       | Day-Ahead (SPOT market) | Early Morning Block| Summer      | Saturday   | 11 July 2015  | 53  |
| 54       | Day-Ahead (SPOT market) | Late morning Block | Summer      | Saturday   | 11 July 2015  | 54  |
| 55       | Day-Ahead (SPOT market) | Early Afternoon Block | Summer   | Saturday   | 11 July 2015  | 55  |
| 56       | Day-Ahead (SPOT market) | Rush Hour Block    | Summer      | Saturday   | 11 July 2015  | 56  |
| 57       | Day-Ahead (SPOT market) | Off-Peak 2 Block   | Summer      | Saturday   | 11 July 2015  | 57  |
| 58       | Day-Ahead (SPOT market) | Baseload Block     | Summer      | Saturday   | 11 July 2015  | 58  |
| 59       | Day-Ahead (SPOT market) | Peakload Block     | Summer      | Saturday   | 11 July 2015  | 59  |
| 60       | Day-Ahead (SPOT market) | Night Block        | Summer      | Saturday   | 11 July 2015  | 60  |
| 61       | Day-Ahead (SPOT market) | Off-Peak 1 Block   | Summer      | Saturday   | 11 July 2015  | 61  |
| 62       | Day-Ahead (SPOT market) | Business Block     | Summer      | Saturday   | 11 July 2015  | 62  |
| 63       | Day-Ahead (SPOT market) | Off-Peak Block     | Summer      | Saturday   | 11 July 2015  | 63  |
| 64       | Day-Ahead (SPOT market) | Morning Block      | Summer      | Saturday   | 11 July 2015  | 64  |
| 65       | Day-Ahead (SPOT market) | High Noon Block    | Summer      | Saturday   | 11 July 2015  | 65  |
| 66       | Day-Ahead (SPOT market) | Afternoon Block    | Summer      | Saturday   | 11 July 2015  | 66  |
| 67       | Day-Ahead (SPOT market) | Evening Block      | Summer      | Saturday   | 11 July 2015  | 67  |
| 68       | Day-Ahead (SPOT market) | Sun Peak Block     | Summer      | Saturday   | 11 July 2015  | 68  |
| 69       | Week Futures          | Baseload          | Winter      | Monday to Sunday | 26 January 2015 to 1 February 2015 | 69 |
| 70       | Week Futures          | Peakload          | Winter      | Monday to Sunday | 26 January 2015 to 1 February 2015 | 70 |
| 71       | Week Futures          | Baseload          | Summer      | Monday to Sunday | 6–12 July 2015 | 71 |
| 72       | Week Futures          | Peakload          | Summer      | Monday to Sunday | 6–12 July 2015 | 72 |
### Table A2. Bid classifications.

| No. | Market Types            | Bid Types              | Block Times (h) |
|-----|-------------------------|-----------------------|-----------------|
| 1   | Day-Ahead               | Middle-Night Block    | 01–04           |
| 2   | Day-Ahead               | Early Morning Block   | 05–08           |
| 3   | Day-Ahead               | Late morning Block    | 09–12           |
| 4   | Day-Ahead               | Early Afternoon Block | 13–16           |
| 5   | Day-Ahead               | Rush Hour Block       | 17–20           |
| 6   | Day-Ahead               | Off-Peak 2 Block      | 21–24           |
| 7   | Day-Ahead               | Baseload Block        | 01–24           |
| 8   | Day-Ahead               | Peakload Block        | 08–20           |
| 9   | Day-Ahead               | Night Block           | 01–06           |
| 10  | Day-Ahead               | Off-Peak 1 Block      | 01–08           |
| 11  | Day-Ahead               | Business Block        | 09–16           |
| 12  | Day-Ahead               | Off-Peak Block        | 01–08 & 21–24   |
| 13  | Day-Ahead               | Morning Block         | 07–10           |
| 14  | Day-Ahead               | High Noon Block       | 11–14           |
| 15  | Day-Ahead               | Afternoon Block       | 15–18           |
| 16  | Day-Ahead               | Evening Block         | 19–24           |
| 17  | Day-Ahead               | Sun Peak Block        | 11–16           |
| 18  | Week Futures            | Peakload Block        | 08–20 (Monday–Friday) |
| 19  | Week Futures            | Baseload Block        | 01–24 (Monday–Sunday) |

### Table A3. Bid prices [45].

| Bid Types  | Prices (€/MWh) | Bid Types  | Prices (€/MWh) | Bid Types  | Prices (€/MWh) |
|------------|----------------|------------|----------------|------------|----------------|
| MWMN       | 26             | SWMN       | 26.64          | MSMN       | 22.52          | SSMN           | 35.23          |
| MWEM       | 37.5           | SWEM       | 25.4           | MSEM       | 28.12          | SSEM           | 29.84          |
| MWLM       | 48.3           | SWLM       | 29.14          | MSLM       | 37.16          | SSLM           | 30.43          |
| MWEA       | 44.28          | SWEA       | 28.5           | MSEA       | 27.52          | SSEA           | 28.26          |
| MWRH       | 41.42          | SWRH       | 40.39          | MSRH       | 47.15          | SSRH           | 33.65          |
| MWOP2      | 27.51          | SWOP2      | 28.81          | MSOP2      | 59.86          | SSOP2          | 41.88          |
| MWBL       | 37.5           | SWBL       | 29.81          | MSBL       | 33.21          | SSBL           | 37.05          |
| MWPL       | 44.67          | SWPL       | 32.68          | MSPL       | 30.78          | SSPL           | 37.28          |
| MWN        | 26.15          | SWN        | 26.11          | MSN        | 21.61          | SSN            | 33.06          |
| MWOP1      | 31.75          | SWOP1      | 26.02          | MSOP1      | 25.32          | SSOP1          | 32.54          |
| MWB        | 46.29          | SWB        | 28.82          | MSB        | 32.34          | SSB            | 29.34          |
| MWOP       | 30.34          | SWOP       | 26.95          | MSOP       | 36.83          | SSOP           | 35.65          |
| MWM        | 49.4           | SWM        | 27.35          | MSM        | 38.76          | SSM            | 31.28          |
| MWHN       | 46.23          | SWHN       | 28.84          | MSHN       | 30.58          | SSHN           | 29.25          |
| MWA        | 42.4           | SWA        | 33.12          | MSA        | 31.84          | SSA            | 28.11          |
| MWE        | 31.84          | SWE        | 33.62          | MSE        | 59.16          | SSE            | 40.7           |
| MWSP       | 44.97          | SWSP       | 28.78          | MSSP       | 29.43          | SSSP           | 28.59          |
| MWF_WBL    | 37.50          | MWF_WPL    | 44.67          | MWF_SBL    | 37.05          | MWF_SPL        | 37.28          |
| TWF_WBL    | 32.94          | TWF_WPL    | 40.21          | TWF_SBL    | 49.02          | TWF_SPL        | 53.83          |
| WWF_WBL    | 28.18          | WWF_WPL    | 30.19          | WWF_SBL    | 29.57          | WWF_SPL        | 27.98          |
| ThWF_WBL   | 26.24          | ThWF_WPL   | 32.7           | ThWF_SBL   | 28.7           | ThWF_SPL       | 28.5           |
| FWF_WBL    | 38.24          | FWF_WPL    | 46.04          | FWF_SBL    | 32.14          | FWF_SPL        | 31.62          |
| SFW_WBL    | 29.81          | SFW_SBL    | 33.21          |           |                |                |                |
| SuWF_WBL   | 29.23          | SuWF_SBL   | 27.9           |           |                |                |                |
Table A4. Total volume each bid types.

| Bid Types | Total Volumes (MWh) | Bid Types | Total Volumes (MWh) | Bid Types | Total Volumes (MWh) | Bid Types | Total Volumes (MWh) |
|-----------|---------------------|-----------|---------------------|-----------|---------------------|-----------|---------------------|
| MWMN      | 44.09               | SWMN      | 56.83               | MSMN      | 0                   | SSMN      | 0                   |
| MWEM      | 0                   | SWEM      | 0                   | MSEM      | 0                   | SSEM      | 14.38               |
| MWLM      | 29.65               | SWLM      | 43.62               | MSLM      | 86.47               | SSLM      | 49.62               |
| MWEA      | 78.79               | SWEA      | 131.34              | MSEA      | 95.49               | SSEA      | 63.16               |
| MWRH      | 95.95               | SWRH      | 136.58              | MSRH      | 82.63               | SSRH      | 57.32               |
| MWOP2     | 89.29               | SWOP2     | 146.11              | MSOP2     | 35.67               | SSOP2     | 24.60               |
| MWBL      | 792.41              | SWBL      | 1255.63             | MSBL      | 1259.63             | SSBL      | 766.42              |
| MWPL      | 227.47              | SWPL      | 347.67              | MSPL      | 277.05              | SSPL      | 189.36              |
| MWN       | 66.14               | SWN       | 85.24               | MSN       | 0                   | SSN       | 0                   |
| MWOP1     | 88.18               | SWOP1     | 113.65              | MSOP1     | 32.62               | SSOP1     | 28.76               |
| MWB       | 124.82              | SWB       | 204.20              | MSB       | 181.96              | SSB       | 112.77              |
| MWOP      | 200.08              | SWOP      | 304.41              | MSOP      | 92.50               | SSOP      | 66.13               |
| MWM       | 0                   | SWM       | 0                   | MSM       | 41.87               | SSM       | 30.35               |
| MWHN      | 49.99               | SWHN      | 85.26               | MSHN      | 105.20              | SSHN      | 60.88               |
| MWA       | 96.33               | SWA       | 141.90              | MSRA      | 90.38               | SSA       | 63.45               |
| MWE       | 132.53              | SWE       | 208.68              | MSE       | 74.46               | SSE       | 54.06               |
| MWSP      | 93.61               | SWSP      | 153.15              | MSSP      | 148.25              | SSSP      | 93.61               |
| WF_WBL    | 6379.94             |           |                     |           |                     |           |                     |
| WF_WPL    | 2129.39             |           |                     |           |                     |           |                     |
| WF_SBL    | 4817.15             |           |                     |           |                     |           |                     |
| WF_SPL    | 1398.66             |           |                     |           |                     |           |                     |

Table A5. Market categories.

| No. | Market Categories                  |
|-----|-----------------------------------|
| 1   | Day-Ahead Monday Winter           |
| 2   | Day-Ahead Monday Summer           |
| 3   | Day-Ahead Saturday Winter         |
| 4   | Day-Ahead Saturday Summer         |
| 5   | Week Futures Winter               |
| 6   | Week Futures Summer               |

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