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Revenue Model for Virtual Clusters within Smart Grids

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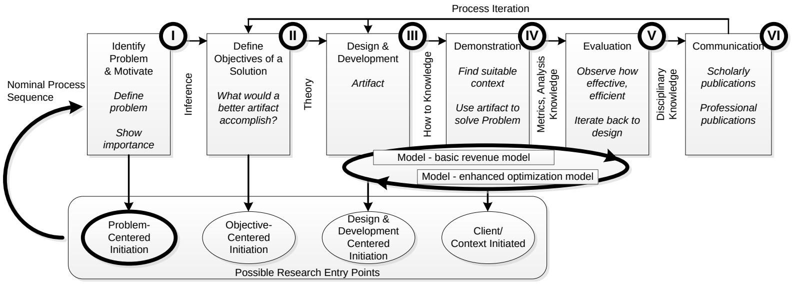

Energy output compared to average	Generated energy [kWh]	LCOE$_{short}$ [€/kWh]	Weighted costs [€]
0%	0	-	-
10%	14.04	0.5841	-4,13
20%	28.08	0.2920	-0,06
30%	42.12	0.1947	4,02
40%	56.16	0.1460	8,09
50%	70.20	0.1168	12,16
60%	84.24	0.0973	16,23
70%	98.28	0.0834	20,30
80%	112.32	0.0730	24,37
90%	126.36	0.0649	28,44
100%	140.40	0.0584	32.52
110%	154.44	0,0531	36,59
120%	168.48	0,0487	40,66
130%	182.52	0,0449	44,73
140%	196.46	0,0417	48,80
150%	210.60	0.0389	52.87

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Abstract

The concept of smart grids and virtual clusters become more and more significant in regard of the energy transition of the German and the European network. Obviously, the market entrance barriers for such a system are enormously high. Not least the investment costs for an implementation of the necessary structures are one of the most relevant impediments. It is important to have a possibility to quantify the cost-benefit structure of virtual clusters. In this paper a dynamic optimization model is designed and tested to answer the question of the profitability potentials of virtual clusters in a regional context within a low voltage network. Additionally, different extension possibilities are considered.

1 Introduction

The energy market in Europe and in Germany is within a phase of change. The European Union (EU) declared in December 2008 the climate and energy package, the so called 20-20-20 targets, with the goal to become a highly energy efficient economy with a low carbon emission. The first key objective which shall be reached in 2020 is a 20% reduction of the carbon dioxide-emissions from the respective 1990 levels of the single EU member states. Furthermore, the energy supply provided by renewable energy resources shall cover 20% of the total energy consumption within the EU. Moreover, the energy efficiency of all member states of the EU shall be improved by 20%.

One idea to achieve these targets is the prospective use of an intelligent distribution and allocation grid, the so called Smart Grid, and the related implementation of virtual power plants to generate decentralized electricity. Simultaneously the usage of renewable energy is increased. At the low-voltage-area, also called the local level, the focus lies especially on the participation of small-scaled users and producers of electric energy and their roles within a Smart Grid. The question is whether the German electricity market can be changed and Smart Grids can be implemented successfully.

The topic of this paper is the creation of a revenue model for virtual clusters at the local level. The focus lies on the profitability for the participants. First a general equation system will be developed, to create a possibility to calculate different configurations of renewable electricity systems and their revenue potentials. Later an example calculation will be done to show how the model works and to evaluate the revenue potential of the configuration example. With the help of these results it shall be evaluated up to what extent the idea of Smart Grids is fit for the future from the benefit perspective for small-scaled electricity providers. Furthermore limitations and expand possibilities of the developed model will be analyzed and proposed. We address the following research questions:

(RQ 1) Does a specific virtual cluster at the low-voltage area have the potential to create revenues?

(RQ 2) How can these revenues be quantified?

The remainder of this paper is structured as follows: first, the research background is addressed, including foundations, related work, and research design. In the third section a revenue model is developed. The implemented model is presented and a formal and verbal description of the underlying model and its conditions as well its parameters and variable are given and explained. Section four includes a sample calculation. In section five, the results are discussed, and the theoretical and practical recommendations, as well as limitations are provided. The paper ends with a short conclusion and an outlook.

2 Research Background

The increasing interest in environmental and economic sustainability of societies also reached the the IS research domain when Watson et al. [22] called for more attention to energy informatics and eco-friendliness in 2010. However, the achievements that shaped Green IS as a subfield in the IS discipline were not followed by a sufficient uptake in research [1]. By employing information and communication technology, Green IS helps expand virtual clusters and renewable energies and consequently increases environmental and economic sustainability [16]. The assessment of pilot projects and the set 20/20/20 goals of the European Union lead to a rising interest in this research area.

2.1 Related Work

In this section, publications that conduct economic evaluations of virtual clusters are presented. The aim of this section is to identify interesting approaches, whose fragments can be used to define a revenue model.

Wang et al. [21] proposed an algorithm to generate random topology power grids featuring the same topology based on the found real data during the research process. Furthermore they analyzed the performance of decentralized control mechanisms that can also be used in virtual clusters to find the optimized configuration. The main focus lies on the question of what kind of communication network is needed to support the decentralized control of a smart grid and not on the related costs and revenues of the virtual cluster itself.

Gungor et al. [8] analyzed different possibilities of communication and information structures as well as their specialized advantages and disadvantages. They provided a qualitative overview about possible potentials of different information and communication structures but did not quantify it.

Verbong and Geels [20] used a socio-technical and multi-level theory on transitions to draw important lessons from a long-term analysis of the Dutch electricity system. They analyze technical developments, changes in rules and visions, and social networks that support and oppose renewable options and look at novel renewable energy technologies and structural trends in the existing electricity regime. They concluded that many barriers for a sustainability transition of the electricity system exist, but also they saw some opportunities. However they only considered the possibility of a transition of the Dutch electricity system in general but did not analyze the idea of virtual clusters itself.

The cost-benefit-structure of the implementation of smart meters in the EU has been analyzed by Faruqui et al. [1]. They pointed out that the costs of installing smart meters in the EU can be financed through the enablement of dynamic pricing, which reduces peak demand and lowers the need for building and running expensive peaking power plants. A number of ways to increase the adoption of dynamic pricing have been outlined. The focus lies on the cost-benefits structure of the usage of smart meters and dynamic pricing but the related issue of virtual clusters is not analyzed.

Singh [18] analyzed the need of coordination among electricity generation, transmission, distribution and consumption processes in a smart grid when additional loads Plug-In Hybrid Electrical Vehicles (PHEVs) are considered. The mismatch between generation and consumption and the avoidance of overloading the distribution system components are considered as important challenges. A specific architecture has been developed through a theoretical analysis and mathematical deliberations to solve these problems. The main focus lies on the technical problem of different loads in the PHEVs and the Smart Grid. The economic aspects are not analyzed.

Moslehi and Kumar [12] reviewed the reliability impacts of major smart grid resources such as renewable energy, demand response, and storage. They observe that an ideal mix of these resources leads to a flatter net demand that eventually accentuates reliability challenges further. A grid wide IT architectural framework is presented to meet these challenges while facilitating modern cyber-security measures. This architecture supports a multitude of geographically and temporally coordinated hierarchical monitoring and control actions over time scales from milliseconds and up. The reliability of the major smart grid resources is also important when it comes to a cost-benefit calculation but it is not focused in their paper.

All in all it can be said that several research is done in the field of research of virtual clusters or in a wider sense smart grids. However the cost-benefit structure of a virtual cluster is not quantified yet in detail. The development of a mathematical model has been unattended. So in this paper the economical perspective is considered in regard of the question of the profitability of virtual clusters.

2.2 Research Design

Our research was conducted using DSR principles in order to address relevance and enhance rigor of the research process and results. The design-orientated research process was advised by Offermann et al. [13] and, in particular, Peffers et al. [15]. Additionally, we used key recommendations provided by Hevner et al. [9], [10] and March and Smith [11]. The actual research design is classified as a problem-centered approach according to [15] , see Figure 1.

The lack of studies about the economic potential of virtual clusters in the low-voltage area triggered the development of our revenue model. The importance of a change of the electrical grid in the near future and Smart Grids as the most probable solution for this change stimulated our research further. We initiated our research process by identifying the above-mentioned problem (I). To ensure methodological rigor, foundational information must be assembled from the academic body of literature. We conducted a comprehensive literature review within the fields of energy informatics and the general finance and IS research domain. Additionally, we conducted a targeted review within the DSR domain.

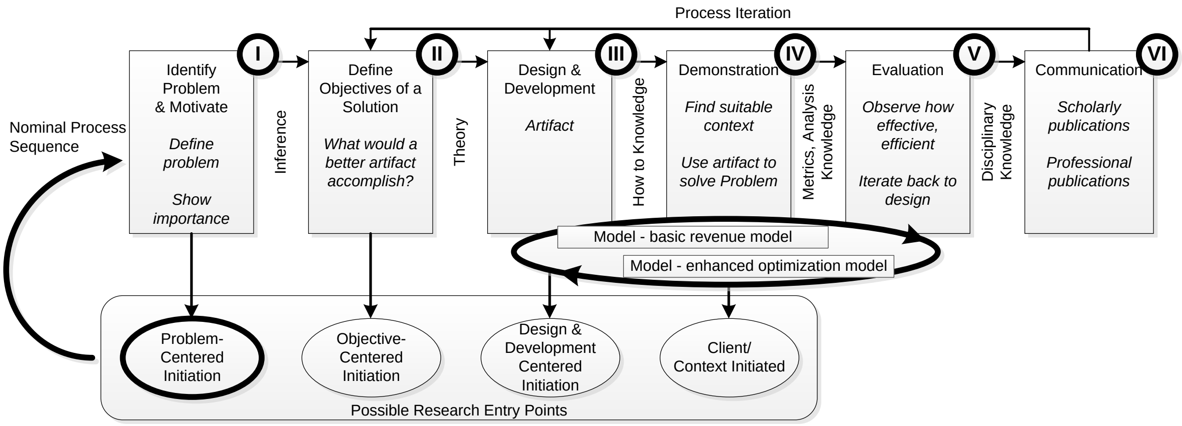

Figure 1: Research design according to the DSR methodology process [15]

According to the research question, the main objective focused on the design, demonstration, and evaluation of artifacts that can provide a basis to quantify the benefit of virtual clusters within smart grids for small scaled energy providers in the low voltage networks (II). With regard to this objective, the practical and scientific input was used to design and evaluate artifacts in a loop of iterations in the design cycle according to [10]. Artifacts can be classified into constructs, models, methods, and instantiations as the result of design-oriented research [10], [11]. After refining the problem domain and defining specific requirements, the first research artifact was designed (III): a basic revenue model. It was limited to central aspects of the complexity of virtual clusters and smart grids itself. This model included only rudimentary parameters and possibilities to customize the project characteristics. For a further development and a more detailed elaboration we used an iterative approach to generate and refine artifacts cyclically according to guideline six, "design as a search process", by [10] (see Figure 1). Thus, the basic model was enhanced with extra parameters and additional auxiliary conditions, resulting in a dynamic optimization model. The DSR process cycles were then completed by more extensive tests of the artifacts to enable the documentation of research results. According to the classification of research methodologies by Palvia et al. [14], a case study in the form of a project value calculation for the energy suppliers to demonstrate (IV) and evaluate (V) the capabilities of the model. Finally, we worked toward publishing our research results (VI).

3 Smart Grids, Virtual Cluster and Revenue Model

3.1 The short-term electricity production costs

In order to develop an equation to calculate the revenues of a virtual cluster the Electricity production costs (LCOE = Levelized costs of energy) of a single generator and sectors have to be quantified through a modulation of equation (1) [6]:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}} \tag{1}$$

Where I_0 are the total investment costs, A_t are the maintenance and variable costs per year t, M_{el} is the produced electricity in time period t (in kWh), i is the calculated rate of interest in % and n is the lifetime. With the help of this equation the electricity costs of different kinds of generation systems can be calculated through dividing the present value of all expenses by the total cash value of the electricity generation. The problem is that the time period in this equation is far too long (one time period equals a year) to be adapted to a model where the configuration of electricity generators should be set in a time period of only a few hours or even minutes. To solve this problem the assumption will be made that the investment costs of an electricity generator are paid through a loan and the payments are divided all over its lifetime. To do this the investment costs have to be discounted to shorter time periods, for example to half-day periods (1 year = 730 half-days) to create a 12-hour-appraisal-system. This can be made with the help of the following equation of amortizing loans [1]:

$$C_{I,x} = \frac{P}{\frac{1}{r}\left(1 - \frac{1}{(1+r)^N}\right)} \tag{2}$$

Where $C_{I,x}$ = Discounted investment costs, P = total price of the energy generator, r = i / 730 and N = lifetime of the generator in years × 730. Furthermore the other variables of the LCOE equation have to be tailored to the shorter time period. Instead of regard the incurring average fix and variable costs in a year as well as the average electricity production within a year, the time period here has to be set also to a 12-hour-period to guarantee a short-timed view. The calculated rate of interest gathers the costs for binding necessary operating capital and can be neglected in the short term. Finally, the assumptions and equations above result in the following equation of a short term electricity production cost equation of an electricity generator x with $C_{I,x}$ as discounted investment costs of energy generator x, $A_{t,x}$ as maintenance costs in period t and $M_{el,x}$ as amount of energy generation of generator x in time period t, here with a time period of 12 hours (t = 12h):

$$LCOE_{short,x} = \frac{C_{I,x} + \sum_{x=1}^{X} A_x}{\sum_{x=1}^{X} M_{el,x}} \tag{3}$$

3.2 Parameters and variables of the model

The mathematical model to calculate the revenues of a virtual cluster and its conditions can be defined as follows:

$$\max \pi = a - C_E \times E_t - C_{I,X} \tag{4}$$

$$a_1 = \sum_{j=1}^{J}(M_{el,j}(s) - r_{in,j}) \times (C_E - C_j) + \sum_{k=1}^{K}(M_{el,k}(w) - r_{in,k} \times (C_E - C_k) + \sum_{l=1}^{L} r_{out,l} \times b \times (C_E - C_l) \tag{5}$$

$$P_t = \sum_{j=1}^{J} M_{el,j}(s) + \sum_{k=1}^{K} M_{el,k}(w) + \sum_{l=1}^{L} r_{out,l} \times b - r_{in,l} \tag{6}$$

$$M_{el,l} = M_{el,l,t-1} + r_{in,l} - r_{out,l} \tag{7}$$

$$P_t + E_t = D_t \tag{8}$$

$$0{,}2 \times D_t \leq \sum_{j=1}^{J} M_{el,j}(s) + \sum_{k=1}^{K} M_{el,k}(w) + \sum_{l=1}^{L} r_{out,l} \tag{9}$$

$$M_{el,l} \leq M_l \tag{10}$$

$$M_{el,l} \geq 0 \text{ , } M_{el,j}(s) \geq 0, M_{el,k}(w) \geq 0, E_t \geq 0 \tag{11}$$

$$r_{in,x} \leq M_l \times y \tag{12}$$

$$r_{out,l} \leq M_l \times x_l \times (1 - y) \tag{13}$$

The used parameters can be described as follows:

a = Weighted energy supply;
b = Level of efficiency of an energy storage;
C_j = $LCOE_{short}$ of the solar stations (j = 1,...J);
C_k = $LCOE_{short}$ of the wind turbines (k = 1,...,K);
C_l = $LCOE_{short}$ of the energy storage (l = 1,...,L);
D_t = Total energy demand in time period t;
E_t = External procurement of energy in time period t;
C_E = External energy price;
$M_{el,j}(s)$ = Energy produced by solar stations (j = 1,...,J);
$M_{el,k}(w)$ = Energy produced by wind turbines (k = 1,...,K);
$M_{el,l}$ = available energy amount within the energy storage (l = 1,...,L);
M_l = capacity of the energy storage (l = 1,...,L);
P_t = Total energy supply in the virtual cluster in time period t;
$r_{in,l}$ = Energy carried into the energy storage (l = 1,...,L);
$r_{out,l}$ = Energy carried out of the storage (l = 1,....,L);
x_l = binary variable (x ∈ {0,1});
y = binary variable (y ∈ {0, 1});

Further explanations to the variables and parameters:

C_j: The costs of solar stations j = 1,…, J mainly are driven by the investment and maintenance costs.

C_k: The $LCOE_{short}$ of wind turbines k = 1,..., K are mainly driven by the investment and maintenance costs.

C_l: Besides of the fix costs of the energy storage l = 1,..., L, the relatively low level of efficiency of energy storages is important. It is clear that the storage only should be charged when there is an overproduction of energy in the system.

D_t: The total energy demand is an external parameter and depends on the size of the area and the number of clients the considered virtual cluster covers.

E_t: If the energy generation of the virtual cluster cannot cover the energy demand, the missing electricity is covered through external procurement of higher tension areas of the Smart Grid.

C_E: The energy price for external procurement is an external parameter.

$M_{el,j}(s)$: The energy production of a solar station j= 1, ..., J depends on the solar radiation (s) that is measured in irradiance and will be given external in this model.

$M_{el,k}(w)$: The electricity generation of wind turbine k = 1, ..., K depends on the wind speed (w).

$M_{el,l}$: The energy amount within the storage l = 1, ..., L depends on the amount of energy that has been carried into it and carried out of it during former time periods and it cannot be negative. It also has a limitation of energy capacity M_l depending on the type and size of the used storage.

$r_{in,l}$: Renewable energy is carried into the energy storage l= 1, ... ,L when the energy generation amount of the virtual cluster is above the energy demand.

$r_{out,l}$: Energy is carried out of the energy storage l= 1, ... ,L when there is a lack of supply within the virtual cluster, in other words, if the supply is lower than the demand.

x_l: Gets one if the $LCOE_{short}$ of the energy storages l= 1, …, L are lower than the external energy price C_E. So it is guaranteed that the stored energy is only used to support the energy supply within the virtual cluster, if it is less expensive than to buy the electricity from the external electricity provider. Simultaneously it is ensured that not all of the stored energy will be carried out at once, because the $LCOE_{short}$ rise with a reduction of the stored energy amount. So the energy level will not fall below a certain level and there is a reserve of energy for emergencies.

y: Gets zero if the total energy production is less than the demand of energy in the virtual power plant. It gets 1 if the energy production of the virtual power plant is higher than its energy demand.

Equation (4) and (5): Goal of the model is to maximize the revenues π and to minimize the external procurement of energy in order to reduce the dependence of the virtual cluster on central power plants and fossil resources. The energy amount that is covered by the electricity production of the virtual cluster has to be weighted to create a connection between the external price and the costs of electricity generation of the single energy generators. The equation describes the profit that can be made with the single electricity generators in time period t. The electricity amount that is produced by the single generators deducting the amount these generators carry to the storages is multiplied with the difference between its production costs and the price of external electricity. So it shows the profit or the loss of the single generators with the use of opportunity costs. For example if the production costs are lower than the external price the price difference times the amount of the produced energy gives the profit of the regarded electricity generator. If the external price is lower than the production costs the product gets negative and results into losses.

Equation (8): The total energy supply in time period t has to be controlled together with the external electricity procurement by the smart grid operator to be equal to the total energy demand. Therefore the configuration of electricity generator has to be optimized, within this model the main decision lies within the question whether electricity out of the virtual clusters generation is used instantly or whether the electricity demand should be covered by external sources. If the price for external electricity is lower than the electricity production costs within the smart grid, the operator has to anticipate this and has to obtain the cheaper electricity in order to maximize the profit or in this case to minimize the losses. The electricity generation that takes place during these times is carried into the energy storages and is used later, e.g. in times where the external energy price is relatively high.

Equation (9): This equation puts the condition that at least 20% of the energy demand has to be covered by renewable energy generated within the virtual cluster. If the momentary energy generation is not high enough the remaining demand has to be covered by electricity saved in the energy storages. The purpose of this condition is to follow the 20/20/20 targets set by the European Union.

4 Case Study: A Sample-Calculation

In this chapter the developed revenue-model will be tested and used to decide whether an implementation of a Smart Grid into a local area could be profitable or not. The data used in the following example will be based on different outlooks, regarding the spread of the single generator types, electricity price and other variables, for the year 2020.

It is assumed that the regarded virtual cluster covers a small village with several households. The average electricity consumption of households is assumed to be 5000 kWh per year [19]. This leads to an average electricity consumption of 14 kWh per day per household, with a number of 100 households in total. So the average demand is defined as D = 1400 kWh/d. Of course the actual demand will differ and so D is assumed as a benchmark for the aggregated demand of two 12-hour-periods. The average electricity price in 2020, including taxes and EEG, will be about 29 c/kWh [4]. So the external energy price is set to **C_E = 29c/kWh**. To calculate the electricity production, the combination of energy generators and storages has to be defined in the following.

The energy supply by photovoltaic stations will rise to an amount of 10% of the total energy supply until 2020 [17]. This equals in average an install of 54 kW power or 432-540 m² of solar panels in the sample village. Per kW installed power a general solar station can generate 950 kWh per year in average. Today 1 Wp installed power costs 2.70€ but in 2020 the costs are likely to be lowered to 1.40 €/Wp [17]. This equals to a price of 1400 €/kWp. So the installation costs of 54 kW power capacity are about 75600 €. In use of equation (2) the discounted investment costs of the solar sector are about $C_{I,J}$ = 8.20 € per time period t, with a discount rate i = 5.00% and a total lifetime of the solar panels of 20 years. The variable costs are assumed to be fairly low in the short term and so they can be neglected in our case study. Table (1) shows the possible revenues of the installed solar panels in regard of their average generation possibilities. It is shown, that the solar sector starts to earn profits in comparison to an external procurement when the energy output is at least 30% of the average value.

An outlook for wind energy prognosticates an onshore wind energy installed power amount of 45 GW in 2020 [1]. This equals to an energy supply of 112 TWh generated by wind energy. This is about 2 % of the total energy demand of the private households in Germany. 20% of the energy demand in our example equals to 280 kWh that have to be supplied by wind energy. Theoretically, an amount of 41 kW installed capacity should be enough to cover the demand of 280 kWh per day. However, the average wind speed in Germany at a height of 10-15 m, which is assumed as the height of the houses and the height of the wind turbines, is with an average of 4-5 m/s too low to match the demand. So it is assumed that the amount of installed power has to be at least 50 kW. In this example 10 wind stations, each with a nominal capacity of 5 kW are installed. The investment costs for one station are about 27050 € for one plant and consequently 270500 € for 10 plants [23]. With equation (2) the discounted investment costs are calculated as **$C_{I,K}$ = 29.31 €** per period. The variable costs are very low and are neglected in the short period. The electricity production in dependence of the wind speed of the used wind turbine (WESpe 5.0) [23] is presented in table (2).

Energy output compared to average	Generated energy [kWh]	LCOE$_{short}$ [€/kWh]	Weighted costs [€]
0%	0	-	-
10%	14.04	0.5841	-4,13
20%	28.08	0.2920	-0,06
30%	42.12	0.1947	4,02
40%	56.16	0.1460	8,09
50%	70.20	0.1168	12,16
60%	84.24	0.0973	16,23
70%	98.28	0.0834	20,30
80%	112.32	0.0730	24,37
90%	126.36	0.0649	28,44
100%	140.40	0.0584	32.52
110%	154.44	0,0531	36,59
120%	168.48	0,0487	40,66
130%	182.52	0,0449	44,73
140%	196.46	0,0417	48,80
150%	210.60	0.0389	52.87

Table 1: Revenues of the Solar Sector at Different Generation Levels

Wind speed [m/s]	Power capacity (1 turbine) [kW]	Power output per time period (10 turbines, 12 hours) [kWh]	LCOE$_{short}$ [€/kWh]	Weighted costs [€]
0 - 1	0	0	-	-
2	0.02	2.4	12.2125	-28.61
3	0.10	12	2.4425	-25.83
4	0.40	48	0.6106	-15.39
5	0.60	72	0.4071	-8.43
6	1.20	144	0.2035	12.45
7	1.85	222	0.1320	35.07
8	2.70	324	0.0905	64.65
9	3.50	420	0.0698	92.49
10	4.70	564	0.0520	134.25
11-14	5.00	600	0.0489	144.69

Table 2: Revenues of the Wind Sector at Different Wind Speeds

Equation (2) and (3) lead to the short term electricity production costs of energy generated by wind turbines and their weighted electricity generation costs using the affected part of equation (5). It is shown that wind turbines are for themselves profitable at a wind speed of 5.5 m/s compared with external procurement of the generated electricity. When no energy is generated (0-1 m/s) the wind turbines do not generate any revenues but only costs in the height of their discounted investment costs.

The main energy storage consists of electric vehicles, because there is only a small village in the point of view. It is assumed that in 2020 1 million electric vehicles with an average capacity of 40 kWh are available. From this capacity 15 kWh are assumed to be used for charging or discharging. The lifetime of an electric car is assumed as 5 years. It is approximated that a number of 7 electric vehicles is given in the regarded village. The prices of electric vehicles per kWh are assumed to decrease from 400-500 €/kWh today, to a price of 160€/kWh until 2020 [7]. In the following calculation only the available storing capacity of 15 kWh and its costs are important for the virtual cluster. So the investment costs for the total amount of electric cars in this example are be calculated as 15 kWh × 160 €/kWh × 7 = 16800 €. With equation (2) the discounted investment costs are calculated as **$C_{I,L}$ = 5.20 €** per time period. The short term electricity storing costs also are calculated with equation (3) with the difference that not the generated energy but the stored electricity is used in the denominator. Finally, it can be said that the coverage of energy demand through stored electricity is profitable as long as more than 18 kWh are stored. This number appears when the discounted investment costs per period are divided by the external energy price of 0.29 €. The level of efficiency is defined as **b = 0,9** for lithium ion batteries which will be most likely used in the electric cars [7]. The maximum level of stored electricity lies at 105 kWh. The calculation is performed by taking respective values of tables 1 and 2 and enter them into the equations of the revenue model. The values of the storage sector have to be set for each calculation with regard to the constraints.

Example: wind speed (w = 10 m/s), solar radiation (s = 40% of average value), stored energy ($M_{el,l,t-1}$ = 70 kWh), Demanded energy (D_t = 890 kWh). First, the demand of external energy in period one will be calculated with the help of equation (6) and (8):

$$
\begin{aligned}
P_t &= M_{el,\,J,1} - r_{in,\,J,1} + M_{el,\,K,1} - r_{in,\,K,1} + r_{out,\,L,1} \times b \\
&= 56.16\text{ kWh} - r_{in,\,J,1} + 564\text{ kWh} - r_{in,\,L,1} + r_{out,\,L,1} \times 0.9 \\
D_t &= 890\text{ kWh} > P_t = 620.16\text{ kWh} + r_{out,\,L,1} \times 0.9 - r_{in,\,L,1} \\
D_t &= P_t + E_t
\end{aligned}
$$

As a consequence it follows that $r_{out,L}$ = 70 kWh – 18 kWh = 52 kWh because the demand cannot be covered by the generated electricity. So E_t = 890 kWh - 672.16 kWh = 217.84 kWh, $r_{in,L}$ = 0 kWh. The short term electricity storage costs rise with every unit of electricity that is carried out of the system. Here the calculation will be simplified through taking the average costs. The average costs can be calculated through the addition of the first and the last value and division by two:

$C_{L,t} = (C_{l1} + C_{l2}) / 2$
$C_{l1} = C_{I,L} / M_{el,L,1}$ = 5.20€ / 70 kWh = 0.0743 €/kWh
$C_{l2} = C_{I,L} / M_{el,L,2}$ = 5.20€ / 18 kWh = 0.29 €/kWh
$C_{L,2}$ = (0.0743 €/kWh + 0.29 €/kWh) /2 = 0.182 €/kWh

The revenues in period one will be calculated with equation (5) and (4):

$$a_t = \sum_{j=1}^{J}(M_{el,j}(s) - r_{in,j}) \times (C_E - C_j) + \sum_{k=1}^{K}(M_{el,k}(w) - r_{in,k} \times (C_E - C_k) + \sum_{l=1}^{L} r_{out,l} \times b \times (C_E - C_l)$$

The values of the weighted electricity generation costs can again be taken out of tables (2).

a_t = 8.0864 € + 134.25 € + 52 kWh × 0.9 × (0.29 – 0.182) = 147.39 €
$\pi_t = a - C_E \times E_t - (C_{I,L} + C_{I,K} + C_{I,J})$
π_t = 147.39 € - 0.29€/kWh × 217.84 kWh – (5.20€ + 29.31€ + 8.20€) = + 41.51€

Considering external procurement only the demand of 890 kWh with the price of 0.29 €/kWh would create costs of 258.10 € for the virtual cluster. Thus the virtual cluster in total generates 41.51€ instead of costs of 258.10 € which creates a difference of 299.61 € in this example calculation.

5 Discussion and Limitations

During the former chapter a model has been developed and tested with the help of a specific example in order to determine the profitability of small-scaled virtual clusters. In this process some assumptions have been made that delimitate the possible applications as well as the validity of the model. For example the model is focused on certain electricity generation dimensions and does not refer to fossil energy, because this part is assumed to be an external parameter. Nevertheless the probability of systems like thermal power stations or bio-gasoline plants taking a big part in smart grids is very high and so the developed model is not complete. These parts have to be added later to have a complete view over the virtual cluster and its possibilities. Furthermore, it only focuses on electricity generation and neglects the part of heat energy, which should be added, when the model is used in a bigger dimension to generate more reliable and realistic results. The model only regards to one possibility of electricity storages, the electrical vehicles. However, it can be said that this option of electricity storing only covers a small amount of electricity. Even in this small-scaled model it is not possible to collect enough electricity to create remarkable effects in following periods. So it would be very important to integrate other storage options like heat-pumps or batteries with high capacity. The time periods of twelve hours still are very rough and cannot be used to calculate the electricity generation of the virtual cluster in very short time periods, which would be a precondition for a fast decision making system regarding the controllable energy sector. The same problem is located at the side of demand. The electricity consumption has been calculated over estimated, average amounts. In the model they are given as external parameters and should be replaced with data from installed smart meters so that the supply can be adjusted to the demand in a short time interval. To put the model to the dimension of the smart grid itself and to add an ex-ante view in order to create a decision making system that can help to estimate the needed amount of generated electricity, some other factors have to be integrated into the model. One possibility for example would be a direct connection of the control station of the smart grid to a weather forecast in order to estimate the respective electricity amount that is generated by volatile electricity generators and to get ex-ante information about how much electricity have to be produced in the controllable sector. Finally, general cost positions regarding the implementation of a smart grid are neglected in the model, e.g. staff costs, investment costs, maintenance costs. It is assumed that they can be neglected when a small-scaled virtual cluster is regarded, because at this level they probably would not be significant, but they have to be added at least as the model is used in a bigger dimension.

6 Conclusion and Outlook

In this paper, a model with the goal to calculate the revenues of a virtual power plant has been developed and tested. As it can be seen in the case study, a virtual power plant can be even more profitable than centralized energy procurement. So it can be assumed that the needed investment costs for an implementation of virtual clusters could be at least compensated after a few years. Furthermore it is clear that the German grid needs to change to stand the challenges of the future. An adequate as well as a secure energy supply cannot be delivered by the simple extension of electricity generation systems. This would mainly be a waste of resources because the electricity supply cannot be aligned to the electricity demand without an intelligent communication of the single parts of the grid. Furthermore the smart grid research should be expanded to ensure that the system can work practically as well as theoretically, regarding security and organizational aspects. Another point of research that should be followed further to make smart grids more efficient is the target to combine smart grids with the weather forecast to have even an ex ante imagination of how much energy will be produced by volatile energy generators. So it could be possible to estimate the generated energy supply of the volatile sector and to align the energy supply of the controllable sector. Summarized, it can be said that the developed revenue-model, can only be used to give a rough estimation of the costs and revenues of virtual clusters. But with the addition of several variables, it could be possible to develop a profitability-model for virtual clusters on the one hand and on the other hand a short-timed decision making system that could help to increase the efficiency of a virtual cluster due to a better adjustment of electricity supply and demand.

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