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Towards an Allocation of Revenues in Virtual Clusters within Smart Grids

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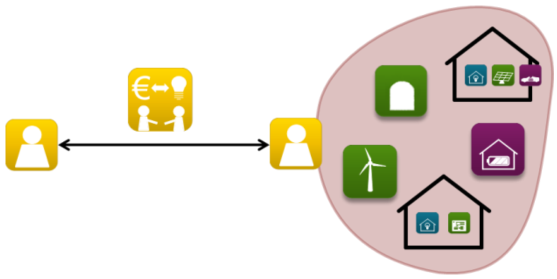

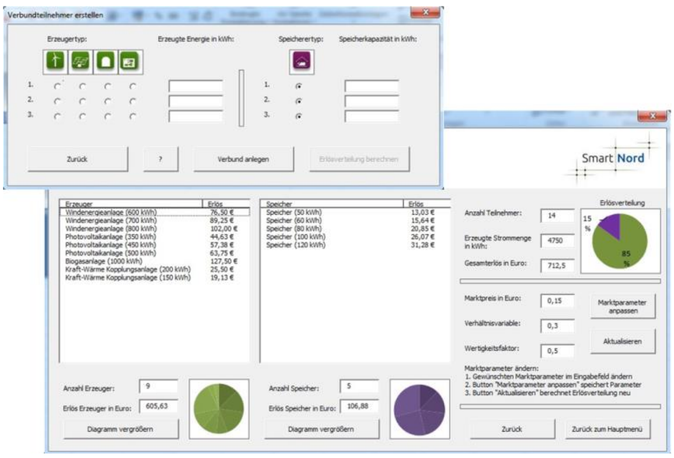

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Abstract

The energy transition in various countries implies a reorganization of the energy sector, related voltage networks and the associated participants. Smard grids will in future play an increasingly important role. Virtual clusters within these networks must meet the economic challenges. We provide support for the allocation of revenues for the participants of those clusters. To that end, research artifacts are constructed and evaluated according to the design science research (DSR) principles. A mathematical model for the allocation of revenues is formulated and forms the basis for an implementation of a software prototype. The applicability of the prototype and the underlying model is demonstrated and evaluated within a case study of a small virtual cluster. According to Green information systems (IS), our DSS contributes to economic sustainability.

1 Introduction

The politically adopted energy transition in Germany in the year 2011 draws far-reaching consequences in the energy sector and makes a rethinking of energy supply indispensable. In order to compensate the nuclear power phase-out in 2050 and simultaneously reduce greenhouse gas emissions, the German energy sector has to be realigned in particular in favor of renewable energies. A power supply mainly based on renewable energy sources, especially on wind energy and photovoltaic power, is difficult to realize due to large fluctuations in the course of a day and a strong dependency of weather conditions. The weather-related problems are only some of the difficulties associated with the transition to renewable energies. The shift from traditional consumers to prosumers is another important factor. Instead of a permanent energy demand, a temporary energy supply to the grid takes place at more and more endpoints within a grid. Consequently, a comprehensive strategy in order to guarantee a stable energy supply through decentralized energy systems is not only an important issue but also a requirement for the success of the energy transition. A mix of photovoltaic systems, wind energy plants, biogas plants, and combined heat and power generation plants represent a promising strategy for the future. Additionally, all grid participants should contribute to the operation of the grid in order to make the grid smart [15]. Smart grids and the subsequent establishment of robust and intelligent electricity supply networks which consider various types of grid participants has recently been adopted and applied by a growing number of researchers [2]. Special attention in the application is put on the aggregation of distributed consumers and producers in virtual clusters to provide active power according to agreed timetables and on the adjustment with network and system services for the fluctuating feed-in from renewable energy systems in real time in consideration of the network load.

Besides a consideration focused on technical aspects, economic aspects also have to be taken into account. Virtual cluster offer a supply of energy on the electricity market to generate revenues. Beyond that, the allocation of revenues to the participants of a virtual cluster is an important issue. Adequate incentives must be created to, firstly, balance the demand behavior of consumers and generators in such grids and, secondly, get generating and storage units to participate in a virtual cluster. The latter aspect is of major importance to accelerate the process of an expansion of smart grids.

Green information systems (IS) and sustainability are becoming major topics within the IS research domain [3]. The increased demand for energy is a chronic problem that demands immediate action. Heavy use of information and communication technology is a factor of higher energy consumption and emission of greenhouse gases (Butler, 2011, p. 2). However, the use of IS does not necessarily imply high energy consumption. On the contrary, intelligent utilization of IS can contribute to higher sustainability. Through an interaction of IT and people, Green IS enables the optimization of processes and products to raise resource efficiency. Thus, direct and indirect conservation of resources and higher sustainability can be achieved.

In existing literature little support for the allocation of revenues for participants of virtual clusters within smart grids exist. To fill this void, in this paper a mathematical model is formulated. In order to enhance usability, the model is implemented in a software prototype. This system enables to set up relevant parameters and to define the composition of a virtual cluster. We address the following research questions:

(RQ 1) How can revenues of a virtual cluster within a smart grid consisting of different types of participants be fairly allocated?

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 concept for the allocation of revenues for participants of a virtual cluster within smart grids is provided. An implemented prototype of an application is presented and a formal and verbal description of the underlying model is given and explained. Section four includes a case study about a project in Brazil. 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 IS research domain when Watson et al. [17] 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]. The allocation of revenues for virtual clusters by using IT and IS helps (indirectly) to increase ecological and economic sustainability by increasing the integration of renewable energies. It aims at the ecological and economic dimension of sustainability concerning energy production and is therefore an example of Green IS [7].

2.1 Related Work

Ideas from cooperative game theory have been used in the broader energy domain for more than a decade. A proven and frequently used approach is provided by Shapley and Shubik [14]. They introduced the Shapley-distribution that estimates the amount of payments to a player depending on a coalition function. The Shapley-Value puts the player in a power relationship which expresses the impact on other players. If a player can contribute to the profit only to a marginal part and success comes regardless of its existence, the Shapley-Value for the player will be zero and he will not be involved in the allocation of payments. Based on the allocation of revenues within a virtual cluster, this represents a major obstacle for an application. The Shapley distribution requires players relating to each other in the same performance ratio. The power rating of energy producers cannot be equated with the capacity of energy storages. The different types of units cannot compete with each other in the Shapley model. Another more general work of Vytelingum et al. [16] focuses on the development of a market-based mechanism and proposed strategies for traders in a smart grid. An approach of coalitional game theory is provided by Yeung et al [18]. They focus on the trading process between market entities in a multiagent system model. Generation, transmitting and distribution of electricity are considered.

A more specific approach is provided by Chalkiadakis et al. [2]. They introduce a game-theoretic approach that considers cooperatives of virtual power plants of rational autonomous agents representing small-to-medium size renewable electricity generating units, which coalesce to profitably sell their energy. They do not only provide the model, but also demonstrate the applicability through a simulation that uses real-world data. Pudjianto et al. [13] focus on distributing energy resources into the electricity network and discuss technical and commercial benefits to the electricity network as a whole. They outline that virtual power plants provide economic advantages for distributed energy resources, e.g. small wind energy plants or photovoltaic systems, and easier access to the electricity market. A coalition formation to initiate a virtual power plant is presented by Mihailescu et al. [9] but they do not provide further details about the mechanisms of individual rationality or incentive compatibilities.

Most of the paper highlight advantages of virtual power plants or virtual clusters but do not provide mechanisms for revenue allocations between the participants of a virtual cluster. One exception is the paper of Chalkiadakis et al. [2]. However, their approach lack on considering energy storages as participants of a virtual cluster. Due to the fundamental differences in the characteristics of storages compared to power generating units, a special consideration of energy storages is necessary.It is of major importance to adapt all relevant conditions in order to develop an allocation function that takes the diversity of individual cluster participants into a detailed consideration. To achieve an allocation that is as fair as possible, a model should be applicable to both, homogeneous and heterogeneous as well as large or small 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.[10] and, in particular, Peffers et al.[12]. Additionally, we used key recommendations provided by Hevner et al. [5], [6] and March and Smith [8]. The actual research design is classified as problem-centered approach according to [12], see Figure 1.

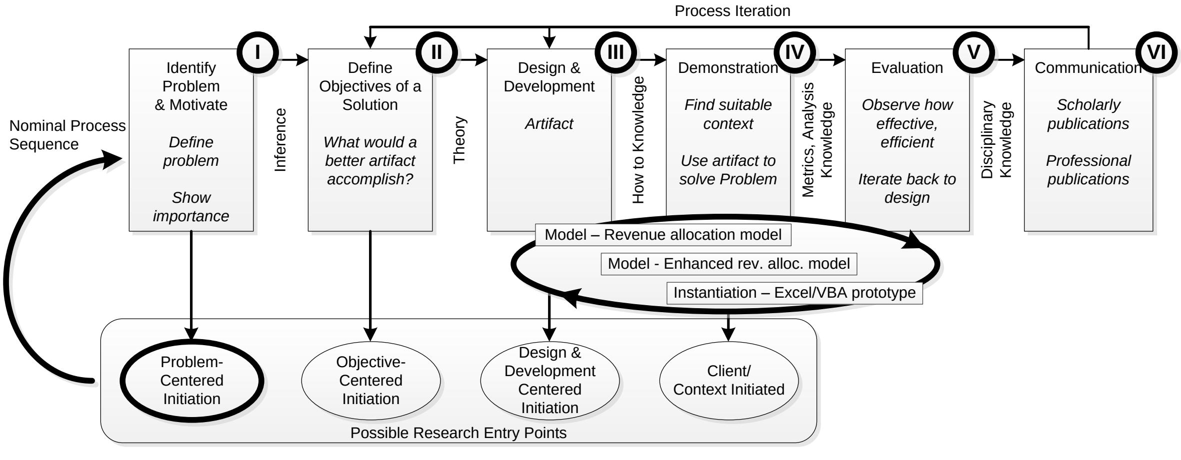

Figure 1: Research design according to the DSR methodology process [12]

The lack of studies about revenue allocations for virtual clusters that do not only consist of energy generating units but also of energy storages triggered the development of our revenue allocation model and its implementation. An easy integration into more comprehensive models or systems that perform a simulation of an entire voltage network provided a further motivation. 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 [5]. We conducted a comprehensive literature review within the field of energy informatics. Additionally, we conducted a targeted review within the DSR domain. According to the research question, the main objective focused on the design, demonstration, and evaluation of artifacts that can provide a basis for an efficient allocation of revenues for all participants of a virtual cluster (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 [6]. After refining the problem domain and defining specific requirements, we used an iterative approach to generate and refine artifacts cyclically according to guideline six, "design as a search process", by [6] (see Figure 1**Fehler! Verweisquelle konnte nicht gefunden werden.**). A basic revenue allocation model was designed as our first research artifact (III). It provides a basic revenue allocation between various energy generating units and energy storages. For a further development and a more detailed elaboration, the basic model was enhanced with extra parameters to adjust the energy market price and the importance of energy storages for the revenue allocation. A classification into constructs, models, methods, and instantiations as the result of design-oriented research is provided by [6]. In addition to the constructed formal model, a prototype of an application was implemented as an instantiation. 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.[11], a case study in the form of an allocation of revenues for a virtual cluster that consist of various different participants was performed to demonstrate (IV) and evaluate (V) the capabilities of the implementation. Finally, we worked toward publishing our research results (VI).

3 Concept of a Revenue Allocation Model

A future design of energy market will most likely not be dominated by fixed feed-in tariff systems. Consequently, virtual clusters within smart grids will become more important on the future energy market and the produced energy has to be sold on the general market. However, the initial situation that a cluster receives a certain amount of money for a delivered energy quantity in a specified period of time remains always the same and is illustrated in Figure 2.

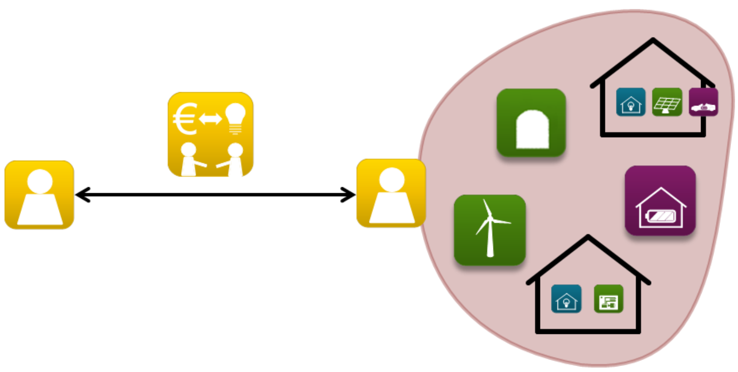

Figure 2: Generation of revenues in a virtual cluster

The virtual cluster has a representative who manages the energy supply, its selling, and the allocation of respective revenues. The revenues have to be fairly and performance-linked divided up to the individual participants of the virtual cluster. However, the difficulty is to find a concept that is applicable to a variety of compositions of the participants on the one hand and on the other hand to different numbers of participants or cluster sizes. In addition, future technical developments and price changes in the acquisition of power plants must be taken into account.

A highly heterogeneous composition of participants ensures a good positioning on the market because short-term climate changes can be reacted to appropriately. For example, if a low-pressure area draws up and clouds darken the sky, photovoltaic systems will lag performance, but this can be compensated by wind turbines by means of more intensive wind. However, a mutual compensation of photovoltaic systems and wind turbines is out of the question because both are too dependent on particular weather conditions. For this purpose, storage units become a member of the cluster. When good weather conditions are prevailing, energy is temporarily stored in storage units, e.g. batteries. Thus, the energy transfer is shifted to another point in time, resulting in a constant power output. Without the ability to store energy produced by renewable energy sources, it will not be possible to accomplish the energy transition. Therefore, it can be stated that storage technology plays a leading role in the prospective energy system.

3.1 Considerations for a Revenue Allocation Model

Creating an effective valuation model requires clarification of defined conditions. We assume that the allocation of revenues is independent of all other processes in the energy system and the energy market. It is a self-contained model. An evaluation of the effectiveness and efficiency of a cluster in terms of sustainable aggregation of participants is not part of the revenue allocation model. Beyond that, it is assumed that all virtual clusters which are bound to the allocation model are efficiently composed. Either, investment and operating costs of each energy plant are not directly considered for the income allocation. A cluster participant always represents a power generating plant or a storage unit. For example, although an individual or a company owns several units within a virtual cluster, each unit counts individually and is separately settled up. The input factors taken into account for an allocation of revenues arise from the number of participants as well as performance and capacity of each plant. The achieved revenues depend on the amount of energy sold at the current market price.

When developing a specific concept the focus is on applicability to different clusters, simplicity or rather comprehensibility and adaptability to future market situations. To simplify measures at first, we implement no distinction between the individual producers. However, a distinction is considered between producers and storages. This results to the fact that the investment and operating costs of various energy producers are basically irrelevant for the allocation of revenues. Only the generated energy is of interest. In particular, the comparison between photovoltaic systems and wind turbines shows that the capital expenditures to produce one kWh of electricity with a photovoltaic system are significantly higher. Since each investor theoretically has the choice whether to invest in wind or solar energy, no considerations of these differences are taken into account.

Additionally, a system without storage units and without the possibility of a load shift would be inefficient. Either a virtual cluster offers only an amount of energy that is below its actual delivery potential to fulfill contracts even in poor weather conditions or it takes penalties into account in case that it cannot supply the promised energy. In any case, regarding the interests of energy producers and energy consumers it is not desirable to be exposed to such load variations. It raises the question how storages can be considered in the allocation of revenues. It is obvious that the energy generating participants cannot divide the total revenues only among themselves. A share of the total amount is passed to the storages. The power generating cluster participants have a higher stability by the accession of storage units at the expense of fewer revenues. However, a model that compensates storage units strictly according to their power output is not suitable. If the weather conditions are optimal and the energy storage is virtually not needed, no compensation would be paid, although the unit was part of the virtual cluster. The incentive for storage units to participate in a virtual cluster would be low and not following a fair concept without discrimination. Consequently, it is necessary to give storage units a share in revenues regardless of the actual use.

To clarify which share is passed to storages, an accurate analysis of storage units is needed. The value of a storage unit within a virtual cluster must be clarified. It depends on how heterogeneous the composition of participants of a cluster is and also on the future technical developments. There are still researches needed to provide suitable storages on prosumer level to store energy in a sufficient extent with high efficiency. Correspondingly, energy storages are expensive to purchase. If the future development of energy storages leads to significant improvements, this will also have great influence on the value of storages in virtual clusters. Therefore, the value of storages remains a variable that can be adjusted according to the level of development. First, the value and the relationship with energy-generating cluster participants is estimated according to current investment costs and titled as storage significance coefficient.

The ratio of the produced energy to the total storage capacity is as important as the significance coefficient for a fair distribution of revenues. To date, it is unknown which storage capacity would be ideal for a particular cluster. It can be assumed that photovoltaic plants have the biggest load variations. Therefore, the size of battery storages has to be clarified. For example, for a photovoltaic system generating 10 kWh per day, the storage must be able to compensate efficiently the night, but also unpredictable darkenings by clouds. Wind energy plants are affected in a similar manner. Since photovoltaic systems are exposed to much greater fluctuations, both systems are strictly bound to different storage requirements and, thus, different optimal conditions over a period of time. However, only one ratio of storage capacities to the total energy production is used for simplicity.

3.2 Mathematical Model

Taking all previously mentioned aspects into account, a mathematical model can be formulated. It is differentiated into two parts. The selection of the applied part depends on whether the virtual cluster contains storage units.

Without any storage units in the virtual cluster:

$$R_p = M * E_p \tag{1}$$

With storage units in the virtual cluster:

$$R_p = M * E_p * \left(1 - S_{pro} * S_{sig}\right) \tag{2}$$

$$R_s = \frac{C_s}{C_{tot}} * R_{tot} * S_{pro} * S_{sig} \tag{3}$$

with:

p = power generating units (1,…, n)
s = storage units (1,…, m)
E = produced energy of power generating unit
R = revenues of individual unit s
R_{tot} = total revenues of virtual cluster
M = energy market price
C = storage capacity of storage unit
C_{tot} = total storage capacity of virtual cluster
S_{pro} = storage proportion
S_{sig} = storage significance coefficient

Initially, the allocation of revenues of a power generating unit is strictly based on the share of the energy production in the virtual cluster. Accordingly, in virtual clusters without storage units, each participant p receives precisely the current market price M multiplied with its generated energy E_p

resulting in the revenues R_p (equation 1). The two variables S_{pro} and S_{sig} indicate the share of revenues which must be given from the energy producers to the storage units. It remains a performance-oriented allocation of revenues for energy producers, even though they do not keep all of the revenues (equation 2). S_{pro} is the proportion of the total storage capacity of a virtual cluster compared to the total amount of produced energy within the considered time period. S_{sig} is the significance factor, which indicates the development level of the storages in order to adjust it independently from the proportion of the storage capacity. As share of $S_{pro} * S_{sig}$ of the total revenues is paid to the storages, it is divided among the storages (equation 3). Each storage unit s will be evaluated according to its capacity C. It will get the share of its capacity to the total storage capacity C_{tot} of the part of the revenues that is intended for the storage units.

3.3 Implementation

A prototype of the presented model is implemented in Microsoft Excel with Visual Basic for Applications (VBA). In order to provide a possibility to instantly access, demonstrate, and evaluate the allocation model, a graphical user interface (GUI) is available. The interface to define the composition of a virtual cluster is presented on the upper side of Figure 3. The results of a revenue allocation for a defined composition of a virtual cluster in combination with the adjustment possibilities for the energy market price and energy storages is presented on the lower side.

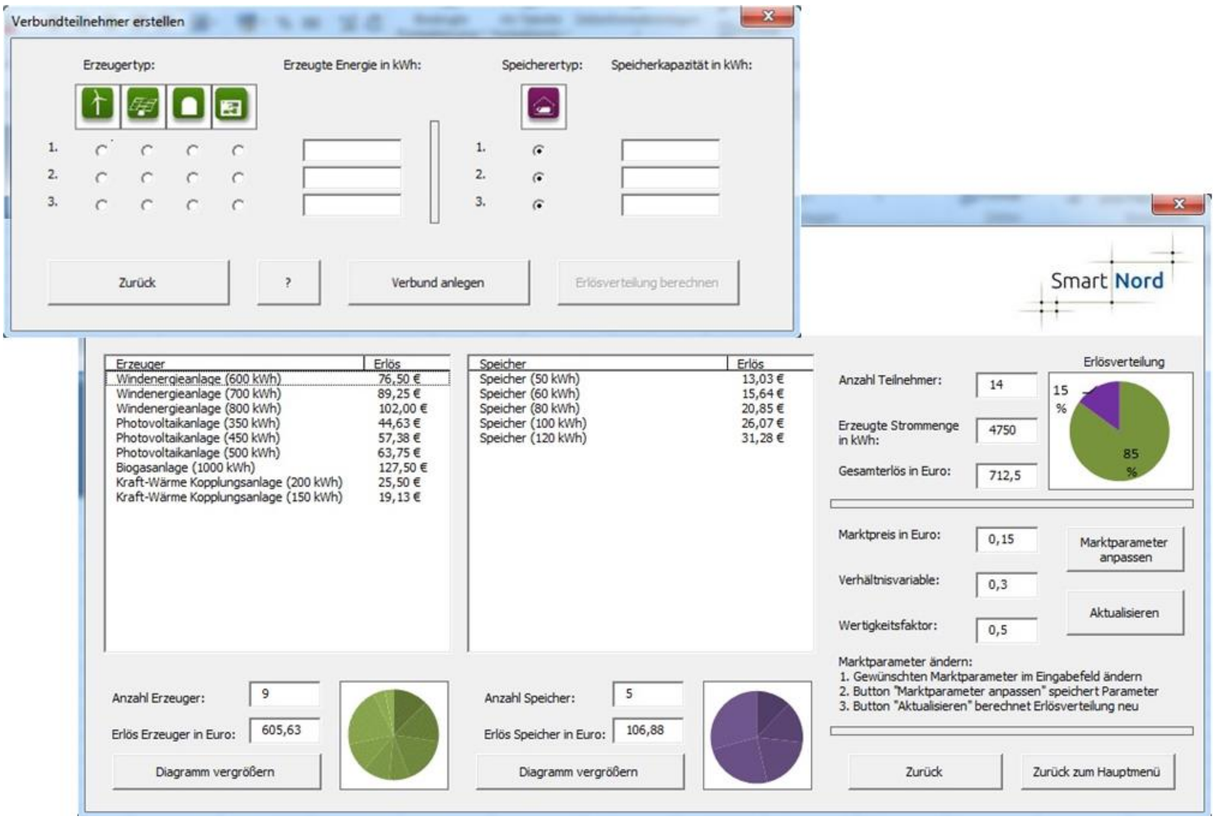

Figure 3: Graphical user interface of the implemented prototype

4 Case Study: Revenue Allocation for a Virtual Cluster

To show the applicability of our research artifacts, the implemented prototype and the underlying model are validated in an example. The assembled virtual cluster is a composition of 16 participants. It consists of wind energy plants (WEP), photovoltaic systems (PVS) and battery storages (BS). Over a period of 24 hours energy of 3350 kWh is sold at the general market. The virtual cluster generates at an assumed market price of 15 cent per kWh revenues of 502.50 Euro. The sold energy is produced among the individual participants as presented in Table 1:

Energy generating units				Storage units			
Type	Generated energy	Amount	Revenues	Type	Capacity	Amount	Revenues
WEP	600 kWh	2	68.40 €	BS	25 kWh	1	3.00 €
WEP	1000 kWh	1	114.00 €	BS	140 kWh	2	16.80 €
PVS	100 kWh	4	11.40 €	BS	200 kWh	2	24.00 €
PVS	175 kWh	2	19.95 €	BS	300 kWh	1	36.00 €
PVS	400 kWh	1	45.60€				

Table 1: Revenues of the energy generating and storage units of the example virtual cluster

The total amount of 502.50 Euro will be allocated to the individual participants using the revenue allocation model. The ratio of storage capacity generated power in this example is 1005 kWh to 3350 kWh and is based on a rough estimate or rather on current customary storage sizes for photovoltaic systems [15]. Thus, the proportion variable S_{pro} is set to a value of 1005 kWh / 3350 kWh = 0.3. As the significance coefficient is a parameter that is not bound to any empirical data but a result of negotiations of the participants, we can freely choose a value. In our example, we set this coefficient to a value of $S_{sig} = 0.8$. This choice guarantees that the acquisition costs of photovoltaic systems and storages are nearly reconciled. Consequently, both types of plants get nearly the same revenues in proportion to their costs. As an example, the calculation of revenues for a photovoltaic system which produces 100kWh is provided. It receives the amount of 11.40 Euro for its energy supply:

$$R_p = M * E_p * \left(1 - S_{pro} * S_{sig}\right)$$

with: $M = 0.15 \text{ €}/kWh,\ E_p = 100kWh, S_{pro} = 0.3, S_{sig} = 0.8$

$$R_p = 0.15 \frac{\text{€}}{kWh} * 100\,kWh * \left(1 - 0.3 * 0.8\right)$$

$$R_p = 11.40 \text{ €}$$

The revenues of all other power plants are calculated analogously. The subtracted amount from the revenues of the power generating plants is the amount which is allocated between the storage units. Each store receives the ratio of its storage capacity to the total storage capacity. For example, the storage with a capacity of 200 kWh awards 24.00 Euro:

$$R_s = \frac{C_s}{C_{tot}} * R_{tot} * S_{pro} * S_{sig} = \frac{C_s}{C_{tot}} * \left(R_{tot} - \sum R_p\right)$$

with: $C_s = 200\,kWh\ ,\quad C_{tot} = 1005\,kWh, R_{tot} = 502.50 \text{ €}, \sum R_p = 381.90 \text{ €}$

$$R_s = \frac{200\,kWh}{1005\,kWh} * \left(502.50 \text{ €} - 381.90 \text{ €}\right)$$

$$R_s = 24.00 \text{ €}$$

5 Discussion and Limitations

We constructed and evaluated research artifacts that determine a fair allocation of revenues for all participants of a virtual cluster within a smart grid. A mathematical model was formulated to fit this task. It splits the revenues between energy generating and storage units and determines the exact amount of revenues for each participant. We implemented the model and created an intuitive IS. Due to the fact that renewable energies within virtual clusters aim at ecological sustainability, we claim that the model and the implementation contribute to Green IS.

Within the provided example we show that under simplified conditions a fair revenue allocation is guaranteed. Nevertheless, it can be debated how to exactly understand the idea of fairness. With the temporary measure of investment costs, the storages have been set in relation to the producers. This is certainly just one interpretation to approximate a fair allocation. Among various views the infinitely adjustable variables make it possible to reach a fair allocation at any time. Assessing the variables in the sample calculation in a different way would change the height of allocation. Due to this high degree of flexibility the model can be easily adjusted regarding the requirements.

In our developed model, a fundamental separation between producers and storages takes place. This separation causes independence with regard to the size and heterogeneity of the virtual clusters. Due to the separate storage-pool, which is composed of the proportional charges from producers, the total number of both, producers as well as storages, is irrelevant because it is always settled up depending on the respective share of their capacities. Proper interpretation of the variables offers an incentive to producers and storages to join the cluster because there is no preference for one type.

For the sustainable aggregation and the profitable operation of virtual clusters in a prospective energy system an equitable allocation concept is of great significance. Without the prior resolving of the payoff function, the union of effective virtual clusters is not possible. The difficulties are basically caused by the fact that energy producers and energy storages contain a core difference. Albeit, energy-generating systems can be valued strictly by their own power output, an output-oriented payoff of storage units would lead to unsatisfactory results.

The lack of progress in battery technologies makes the design of an allocation model more difficult and occasionally results in distorted allocations because of extremely high storage costs. Not only storage development in particular, but also market development in general, must be accommodated in an allocation algorithm. It is of low economic value, to design an inflexible concept which can be no longer applied under future market conditions. Despite the variability, it is necessary to create an accessible, transparent model, which shows the chances and risks of participants in a measurable and comprehensible way. Due to high complexity, it should not have a deterrent effect.

Previously, a concept was developed and applied to example-clusters, which lays the foundation for a balanced and equitable allocation of revenues. In the future the practical realization within the assumed terms and conditions can be brought about, of course, only taking into account the research efforts required. However, it shows the direction in which an allocation of revenues must go, bearing in mind general circumstances and individual specifications of the participating power plants in detail.

The next important step to ensure the prospective application of the concept could be the assignment of specific performance-oriented payoff functions depending on the actual storage requirement of each energy producer. Additionally, the value and significance of storage units or rather capacity in general should be clarified.

Furthermore, this initial concept could also be seen as a help in matters of an efficient and ideal combination of different participants to a cluster. Both, the aggregation of efficient virtual clusters and the allocation of revenues within such clusters are linked to each other very closely.

A further development of our model can increase the complexity. Initially, there was no distinction between the different types of generators. So, there could be not just one identical formula for all producers, but one specifically tailored to the respective producers. In the specific formula, the different storage requirements could be taken into account. In terms of biogas plants, this could mean, that they must pay very little or even no charges to the storage-pool because they are independent of energy storages at all. The main charges would therefore bear photovoltaic systems, since they suffer the heaviest weather-related power fluctuations.

However, load variations, supply potential and actual storage requirements are also a function of the respective supply period. This takes no account in the actual model. The duration of the supply plays an important role in the storage sizing as well as in the allocation of revenues. For example, if delivered over a full day, the storage requirement is highest. Even increasing the supply duration to 48 hours would not result in more storage requirements, due to the cyclical weather conditions and the path of the sun in a day. If the supply period of the calculation example now doubles to 48 hours, the amount of generated energy will double, too. In theory, each plant generates twice as much energy. The storage capacity is not increased, but remains the same. By separating revenues proportionately, this issue is taken to account in the model. Without adjustment of the variables both producers and storages receive twice the amount. Problems occur if it is not supplied over one or more whole days but over arbitrary periods. Thus, a power supply during lunch times would not only result in a small dimensioning of the storage, but most likely also in a much lower usage, too. Unlike a continuous supply over a full day, the variables must necessarily be adapted to ensure an equitable allocation.

The same is valid for inefficient clusters. Reviewing an inefficient cluster with these criteria hardly makes sense. The condition that in the future only optimal clusters participate on the market is only an ideal conception. Assuming that each cluster can be compiled differently, a development of a revenue model is nearly impossible. Thus, this weakness of the model cannot be eliminated in principle, but the approximate compensation by changing the variables can be tried.

The correct interpretation of the variables leads to a very crucial role in this concept. Even in this simple model, any desired allocation can be achieved by varying the parameters. However, there are no reasons not to further develop this model in detail and complexity.

6 Conclusion and Outlook

Important issues concerning virtual cluster within smart grids and Green IS are in need of further research. Within the design-oriented research process, we constructed and evaluated research artifacts to support the complex task of revenue allocations in virtual clusters. A mathematical model was formulated to determine fair revenue allocations for any kind of composition of a virtual cluster. This model is implemented into a software prototype which easily allows data setting and provides a visualization of results. We evaluated and demonstrated the applicability of our prototype and the underlying model in an example of a small virtual cluster. An expansion of renewable energies is supported indirectly by our Green IS and thus it contributes to environmental sustainability.

Following the identified limitations, further research steps are required in regard to our artifacts. The mathematical model can be enriched by additional parameters, e.g. a consideration of the advantages of storage units regarding the balancing of energy supply fluctuations by wind energy plants and photovoltaic systems. Additionally, not only an enhanced allocation of revenues should be implemented, but also an allocation of penalties when individual plants break down and supply contracts of the whole virtual cluster cannot be fulfilled.

Based on our prototype to allocate revenues between all participants of a virtual cluster, implications for further research are outlined. The underlying model can be adopted and refined by other researchers. As virtual clusters within smart grids are As virtual clusters within smart grids are an important issue, the model can be integrated into a comprehensive model that provides a consideration of an entire smart grid.

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