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Towards an Allocation of Revenues in Virtual Clusters within Smart Grids

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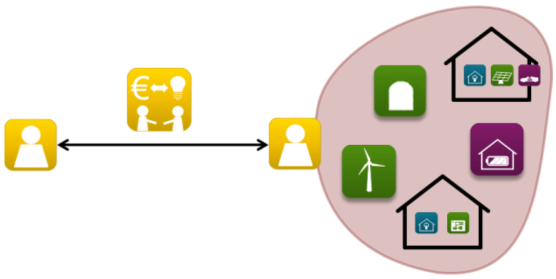

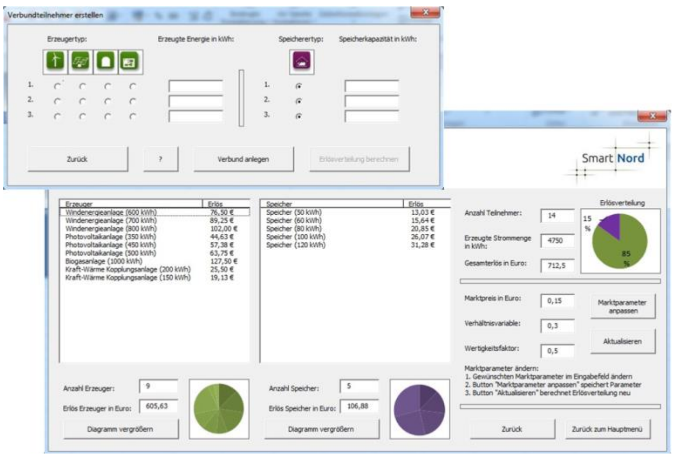

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Abstract

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.

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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