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Energy Cooperatives as an Application of Microgrids: Mulit-Criteria Decision Support for Investment Decisions

by

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ENERGY COOPERATIVES AS AN APPLICATION OF MICROGRIDS: MULTI-CRITERIA DECISION SUPPORT FOR INVESTMENT DECISIONS

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Abstract

The future of energy generation is expected to become increasingly decentralized. Today, many customers are already more than demand units, they also act as energy producers (prosumers) and thus active participants in the energy market. The development of energy cooperatives in recent years undermines this observation. Information and communication technologies (ICT) enable management of energy cooperatives by incorporating smart meter data and energy generation data. This paper presents a MAUT-based multi-criteria decision artifact to provide decision support for energy cooperatives based on microgrids when deciding about an investment in new supply units. The findings of the literature analysis point out that energy cooperatives have economic, ecologic and social goals. However, each cooperative weights the identified goals differently according to its preferences. Within our decision artifact we define measures for the fulfilment of the goals including available data. Thus, the utility for each criterion is calculated and aggregated to an index reflecting the total utility of each new investment, e.g. the utility by an additional photovoltaic plant in the cooperative. Furthermore, we test the developed model with real-world data. The results indicate that our artifact provides useful decision support for energy cooperatives.

Motivation

The Commission of the European Union released the Strategic Energy Technology Plan (SET Plan) in 2007. One of its goals is the development of smart cities that manage local energy production and consumption in an efficient way (SET-Plan, 2007). So far, electricity markets are centrally organized, have high entrance barriers for individuals such as small consumption or supply facilities, and are complex. However, the transition towards decentralization is an ongoing process (Joskow, 2008). Microgrids, also characterized as the "building blocks of smart grids", are perhaps the most promising, novel network structure as they provide a chance for local optimization (Schwaegerl & Tao, 2014a).

The meltdown of three nuclear power reactors in March 2011 in Fukushima was the initiation of ongoing discussions about the future of nuclear energy. In Germany, a huge shift in energy policy started: The government declared to shut down all nuclear reactors by 2022. One solution for overcoming the challenges is to focus on decentralized generation of energy in order to reduce grid expansion expenses and increase the security of supply. Along with the political decisions, regulatory programs were introduced to rise renewable energy production which encouraged customers to build own renewable power plants (Carley, 2009). Concurrently energy cooperatives were set up to "promote the use of renewable energy" (Viardot, 2013). In

Germany for example, in recent years the number of newly founded energy cooperatives increased from 9 in 2006 to 165 in 2013, reaching its peak in 2011 (193) (Yildiz, 2013). So far the topic of energy cooperatives is rarely discussed in research. Energy cooperatives are one driver for decentralization and thus there is a need for research.

Energy cooperatives are an application of microgrids, i.e. one possible organizational form of a microgrid. While there are various definitions of microgrids (Di Zhang, Liu, & Papageorgiou, 2014; Hatziargyriou, 2006-2009; Schwaegerl & Tao, 2014a) we define a microgrid to consist of infrastructure (internal grid), renewable generation and demand (households). A microgrid can have two modes, grid connected and islanded (or standalone) mode (Liang & Zhuang, 2014). The expansion of microgrids can be observed in many parts of the world, as pilot sites were installed and explored in many countries (Kariniotakis, Dimeas, Van Overbeeke, & Frank, 2014; Viardot, 2013). In terms of reasons for setting up a microgrid, our analysis of literature leads to the following result: They are set up to follow the idea of a more sustainable energy system (Schreuner, 2012). Thus, we argue that an energy cooperative has various economic, ecologic and social goals that can be measured by different criteria (Zarghami & Szidarovszky, 2011). The economic goals can roughly be characterized in providing locality benefit, i.e. reduction of transport losses due to shorter distances and selectivity benefit, i.e. lower cost and reduced electricity prices (Schwaegerl & Tao, 2014b). However, this highly depends on local characteristics, e.g. in the U.S. the Fox Islands Cooperative was able to reduce electricity costs (Borst, 2010). The ecologic goals of an energy cooperative are increasing energy efficiency, emission reduction (Parisio & Glielmo, 2012) but cooperatives are also "created to promote the use of renewable energy" (Viardot, 2013). The social goals of an energy cooperative are of a very broad nature, examples of literature are: Creation of research and job opportunities, electrification of underdeveloped areas (Schwaegerl & Tao, 2014b) as well as independence (Alanne & Saari, 2006).

The objective of this paper is to answer the following research question: *How should an energy cooperative based on a microgrid decide on investing in a new generation unit by incorporating available data?* To answer this question we develop a generic and easy to implement tool for decision-making incorporating multiple criteria. According to Krcmar (2005) ICT enables new business models. Therefore, we see a microgrid organized by an energy cooperative as a human-machine system which interacts in terms of monitoring and control. Thus, the coordination and management of the infrastructure of the microgrid is enabled by ICT as diverse data sources need to be collected and used for decision making. Our work is related to Green IS as the artifact incorporates environmental aspects into an IS for decision making (Vom Brocke, Watson, Dwyer, Elliot, & and Melville, 2013). Therefore, the artifact enables environmentally sustainable behavior. We develop the decision support artifact, following design science research guidelines and evaluate it by example (Hevner, March, Park, & Ram, 2004).

Methodology

The described goals of the cooperative can be of conflicting nature, therefore the decision whether to include a new supply unit in the energy cooperative is extremely complex as manifold criteria need to be incorporated. For such multi-objective decisions with conflicting goals the concept of multi-criteria decision analysis

(MCDA) is an expedient approach (Polatidis, Haralambopoulos, Munda, & Vreeker, 2006; Zarghami & Szidarovszky, 2011). MCDA was introduced in the mid-1960's since when there have been many publications on decision making in several areas (Figueira, 2005). The methods of MCDA can be categorized in utility-based methods, where every decision alternative gets a single score and outranking methods which are based on pairwise comparisons of decision alternatives (Polatidis et al., 2006). Especially for energy issues, the methods of MCDA are privileged tools (Klein & Whalley, 2015, Mavrotas, Diakoulaki, & Capros, 2003, 2003; Polatidis et al., 2006). For our research question, we identify the MCDA method MAUT (multi attribute utility theory), which is part of the utility-based method family, as an appropriate method. MAUT was introduced by Keeney and Raiffa (1976), it allows to take into account the individual utility of the decision maker (DM). The method suggests the definition of a utility function for each relevant criterion, which is constructed such that the utility generated by the criterion is between the interval of 0 and 1. The utility value reflects the preferences of DM. At the end of the process, all utility values are weighted and aggregated for each alternative which allows for the comparison of the utility values of the decision alternatives. There are reasons for favoring MAUT. First, we aim for a simple approach and results, which are easy to understand. Furthermore we are interested in reflecting compensatory effects of the different criteria as their utility values might run contrary to each other (Montis, Toro, Droste-Franke, Omann, & Stagl) and we perceive the measure of utility as the basis of a decision very useful. We describe our derived decision artifact (see Figure 2) in the following.

From the perspective of the main grid, the energy cooperative appears as a single profile, reflecting the aggregated demand and supply of all members. In general, the DM can choose between two decision alternatives a0 and a1, i.e. not to invest or to invest in a renewable energy source (e.g. a photovoltaic plant). Thus, when a cooperative decides about including a new supply unit, the fit with the existing profiles according to a cooperative's goals needs to be evaluated. Therefore we introduce the concept of net supply NS_t which is the difference between supply and demand at each point of time. The utility therefore needs to be derived from NS_t.

The corresponding criteria for the identified superior goals of the cooperative are therefore based on NS_t. In the following the utility functions for each criterion are described. As we assume the energy cooperative (which acts as DM) to be risk neutral, the utility functions are linear and monotonic (Neumann & Morgenstern, 2007). The economic utility can be derived from the money gained or lost when electricity is exchanged with the main grid. The proposed model is suitable for cooperatives, which act as price takers. The ecologic utility is expressed by the ratio of non-renewable energy in the cooperative, i.e. when the cooperative needs to buy electricity from the main grid, which is only partially generated by renewable energy sources. The social utility is expressed by the degree of autonomy from the main grid, meaning that each interaction with the main grid reduces utility. Figure 1 shows the utility functions of the three decision criteria.

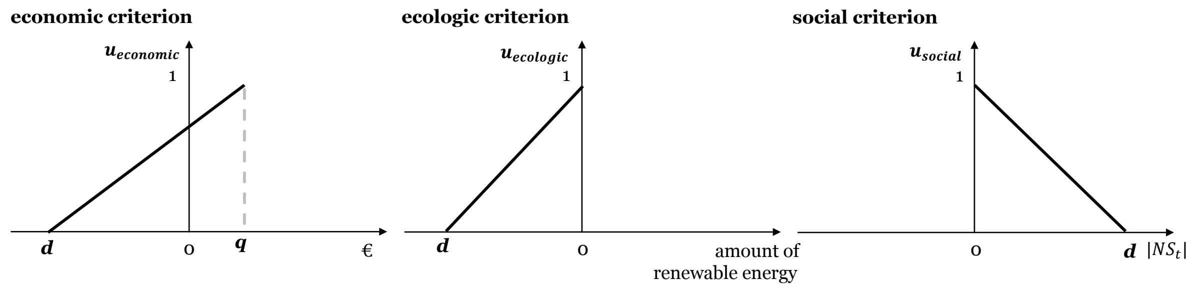

Figure 1: Utility Functions of Economic, Ecologic and Social Criterion

As NS_t differs at each point in time, the utility gained from it is also time-variant. Therefore it is essential to take the utility of every point in time t into account. The utility at each point in time is the weighted sum of the utility values of the criteria. The weights reflect the relative importance of every criterion and need to be defined by the DM.

However, the decision is not just based on one point in time, it is based on a longer period. Consequently, utility values need to be aggregated over time as well. For reasons of simplicity we do this by averaging them. This results in one index, which allows comparison among the decision alternatives and lies between 0 and 1, as it is proposed in the original MAUT method. Thus, when the cooperative decides about investing in a new supply unit, the index is calculated twice, without and also with the new supply unit. By comparing the indices, the decision can be made in favor of the higher index.

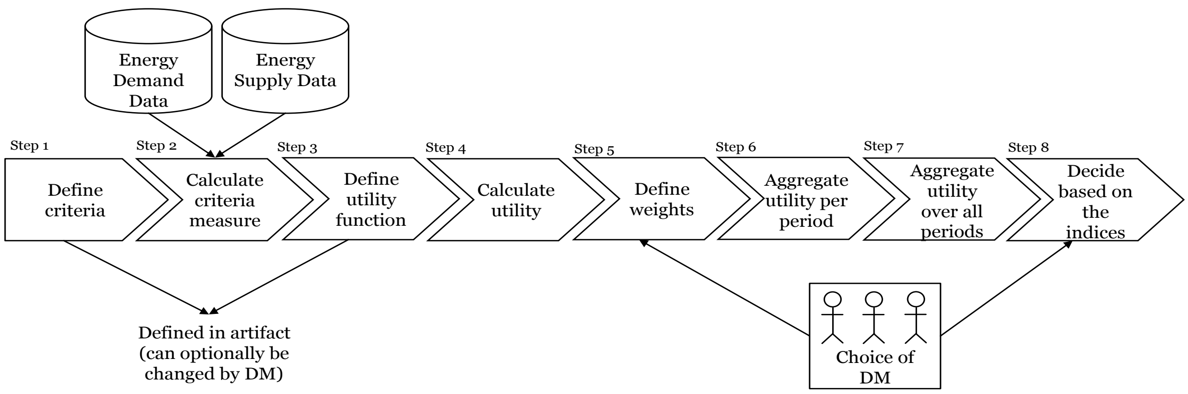

Figure 2: Investment Decision Artifact for Energy Cooperatives

Evaluation and Sensitivity Analysis

We evaluate our decision artifact by applying it to 1,000 fictional energy cooperatives. For constructing those, we use real-world data, e.g. smart meter and renewable generation profiles. The smart meter profiles and generation profiles were collected for every 15 minutes within the mentioned period. The examined period for all data sets is from June 2011 until September 2014, in the following we give an overview about the data used as input for the decision artifact.

- 20 smart meter demand profiles from Germany
- Electricity generation profile from a wind turbine (installed capacity: 1 MW) from Baden-Wuerttemberg, Germany

- Electricity generation profile from a photovoltaic plant (installed capacity: 1 MW) from Baden-Wuerttemberg, Germany
- Electricity spot prices from the EPEX for the market area Germany
- Feed-in information regarding renewable and conventional electricity generation from the Transmission System Operator for Baden-Wuerttemberg, Germany
- Cost information on photovoltaic plants and wind turbines, including fixed cost, variable cost and depreciation from Kost et al. (2013)

For generating 1,000 fictional cooperatives, we randomly choose load profiles from our basic sample of 20, combine them and scale them up to an average demand close to the generation capacity. We include the photovoltaic plant and the wind turbine in the cooperative and subtract the demand profile from the generation profile. Each of the resulting 1,000 cooperatives is treated as decision alternative a0. For getting alternative a1 we choose to add another photovoltaic plant.

We test different weight combinations on each of the 1,000 cooperatives by increasing the weight of the respective examined criterion from 0 to 1 in 0,01 steps and simultaneously reducing the other weights equally. For the tested weight combinations every cooperative gains utility when deciding according to our artifact compared to a naïve DM, i.e. a DM that always invests or rejects. The utility improvement compared to a naïve DM who always invests ranges from 0% to 6.8%. Compared to a naïve DM who always rejects, we observe utility improvements from 0% to 26.2%. This implies that cooperatives with some special weight combinations could suffer from making naïve decisions.

Furthermore, we conduct a sensitivity analysis of the investment decisions on the above mentioned weights for the different criteria. We aim to observe the impact of different weights, and therefore of different preferences of DMs on an investment decision. In Figure 3 we see the number of cooperatives rejecting the decision, dependent on the weights on the criteria. All cooperatives reject the investment decision for a weight of 0.8 and beyond on the economic criterion. This implies that the investment is not attractive from a solely economic point of view. We see that the line for the social criterion is not monotonic. This reflects the need for our artifact best, as this implies an intuitive decision.

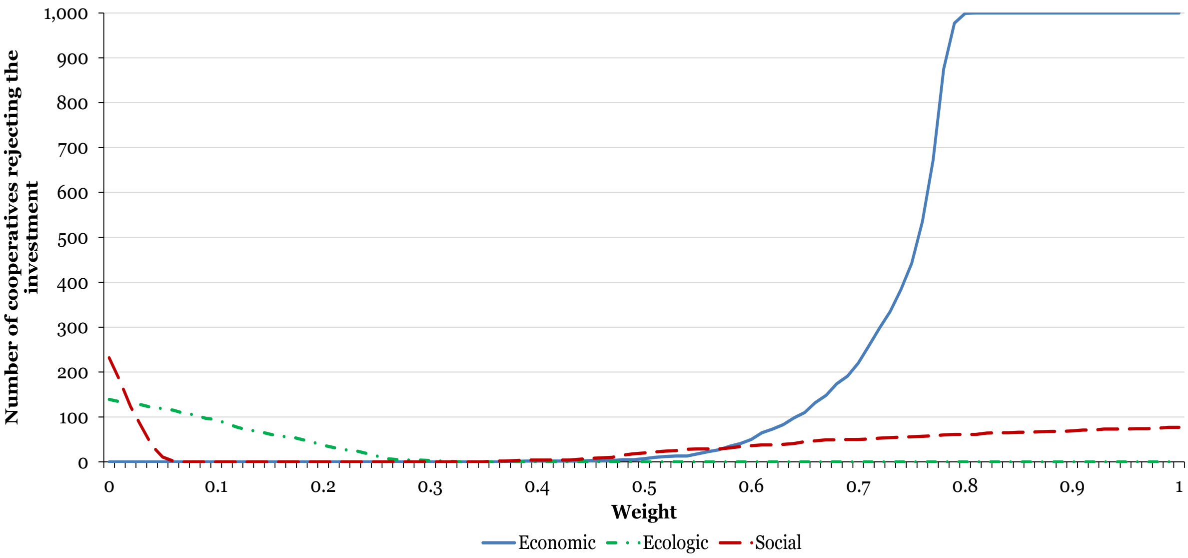

Figure 3: Sensitivity of Investment Decision to the Economic Criterion

Main Results, State of Research and Future Outlook

In this paper we present a decision artifact for choosing the right investment for an energy cooperative. The development of energy cooperatives is strongly related to ICT, as by incorporating available data, new management possibilities arise. Therefore we included available supply and demand data. The complex decision of investing in a new supply unit is not just made on the basis of a net present value approach as know from investment decisions. We develop an artifact for making a decision based on three criteria, reflecting the goals of a cooperative best and show a sustainable approach towards decision making.

The utility functions we propose are intuitive and follow common theorems, which is suitable for the construction of an index. Our evaluation shows, that for the exemplary cooperatives, a decision based on the identified criteria and utility functions makes sense, as the sensitivity of the decision is higher to the ecologic and social criterion. A solely economic focus might lead to a different decision and less utility for the cooperative. Nevertheless, the criteria and the utility functions might differ among cooperatives individually. It could also be possible that there exist more than three criteria. Therefore the decision model is far not exhaustive. However, our artifact enables extension, e.g. other criteria can easily be added. The utility functions for each criterion reflect risk-aversion and try to imply objectiveness. Nevertheless, it can be interesting to interview existing cooperatives and find out how their individual utility functions look like, as this might improve individual decisions.

The method of MAUT is very useful for answering our research question. Nevertheless, the assumption of mutual preference independence is strong and might not always be fulfilled in reality. Future research aims at relaxing the assumption what increases the complexity of decision making.

According to design science research we tried to not just contribute to knowledge by filling the research gap but also tested the artifact with real-world data. We constructed fictional cooperatives from the data available. Future research aims at applying the model to real cooperatives.

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