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Master Thesis

Analysis and Optimization of Local Energy Systems

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1. Introduction

1.1. Motivation

In July 2017 the representatives of the twenty most powerful nations gathered in Hamburg. Besides questions regarding global trade, several hunger crises in Africa, the summit focused on the global transition to sustainable energy. Most recently Trump, president of the United States of America, announced to retreat from the climate agreement of Paris in 2020. The G20 nations were responsible for 77 % of total final energy consumption in 2014. Furthermore, those 20 countries emitted 82 % of all energy-related CO2 emissions in 2012. Considering these statistics the global responsibility of the G20 nations is clearly evident [32]. Therefore, the transition to a sustainable energy system with a high share of renewable energy sources is highly relevant and important.

An alteration of the global energy system and energy supply is necessary in order to achieve nations' climate and energy goals which were set by the Kyoto protocol in 1998. According to Holstenkamp and Radtke four global pillars exist which induce a transformation process of the present-day energy system. The first pillar states the limits of growth. Scarcity of fossil resources becomes increasingly relevant. The Club of Rome presented negative as well as rather optimistic predictions of the run-time of fossil resources, but there is broad agreement in literature that it is essential to shift to an energy system more based on renewable resources. The second pillar includes the liberalization of energy markets since countries started to restructure their energy markets in the 1970s. Germany initiated the process by separating the grid operators from the energy suppliers in 1998. The monopolies of certain regional energy suppliers vanished. Furthermore, the third pillar affects the topic of climate change. A broad agreement in the literature gives evidence that anthropogenic sources are the main driver of climate change. Especially the energy industry caused about 85 % of all CO2 emissions of Germany in 2015 which indicates that a high potential for savings exists. Lastly, the fourth pillar regards the rapid advances in technology. New technologies facilitate an economic home energy consumption which leads to an increase in autonomy of households. Moreover, the process of digitalization and automation leads to smart home networks interacting with the grids [21].

The government of Germany encounters the transition process of the energy system by implementing various resolutions. The nuclear phaseout until 2022 is one of the most prominent resolutions. Furthermore, Germany is subject to energy and climate targets concluded by the European Union (EU). In 2009 the EU adopted three commitments for every EU member to fulfill by 2020. Firstly, greenhouse gas emissions have to be reduced by 20 %. Secondly, renewable energy sources have to reach a share of 20 % of final energy consumption. Thirdly, the energy efficiency has to improve by 20 % in general [45]. These are the medium-term targets for Germany. Moreover, the long-term scenarios call for even more ambitious targets, namely the reduction of greenhouse gas emissions by about 80 to 95 percent until the year of 2050. That profound change will cause total costs of about 1.100 billion € in the most cost-efficient scenario [19]. According to calculations of the federal government of Germany the energy transition will require 550 billion € and additional 300 billion € for the pertinent equipemt of private households [9]. Either way, the energy transition of Germany appears to be a cost-intensive project which can only be accomplished by an incorporation of government, economy and society.

Private households energy consumption almost equals the total energy consumption of the transportation as well as the industrial sector in Germany. Slightly more than a quarter of the total energy consumption is accounted for by the households [1]. Hence, the integration of citizens into the process of change is essential to raise acceptability, awareness and willingness to participate [6].

As explained in more detail in section 2.1 households participate as producers as well as consumers in the energy market. Decentralized energy production turns into a subject of high relevance but at the same time uncertainty when the distribution of local energy systems fails. Today energy providing companies, communities as well as small businesses and households have access to the energy market. Small energy systems on a household base provide an opportunity for house owners to operate in the energy market. In case the dissemination of local energy systems fails and the liberalization of the energy market continues, the awareness of house owners regarding their opportunities and chances should be enhanced.

Several sources mention the lack of understanding the decision-making process of households with respect to private energy production [10][2][13]. Nonetheless, various studies reveal potentials in local energy systems under certain conditions [28][35]. As the process of digitalization progresses and technology advances rapidly the analysis of local energy systems should be expanded on a base of the current status.

1.2. Structure and Approach

To create an energy system which runs independently of fossil energy sources it is necessary to emphasize the current technological solutions. Therefore chapter 2 introduces the emerging concept of prosumage. In addition, five technical components build up the foundation of a local energy system which utilizes only electrical power. These components cover the entire energy, heat, water demand as well as the requirement of mobility of a household. Basic descriptions and explanations of technical processes deepen the understanding of the components. Furthermore, recent developments and market prices are illustrated. The third chapter summarizes three recent studies which analyze local energy systems by using different approaches and assumptions. Since all studies originate from German Institutes, the application refers to local energy systems in Germany. As a result, the findings of the presented studies provide a reference which is later used to compare the results of the developed analysis. The fourth chapter introduces a new approach to analyze local energy systems. After defining the concept and input data the main operating concept forms the centerpiece of the entire analysis. Thereafter, several scenarios with different conditions implement the developed approach. At this point the findings of previous studies are incorporated to render a comprehensive comparison. Finally, chapter 6 summarizes essential conclusions and tries to give an impulse for future research.

6. Conclusions and Outlook

In order to reflect and evaluate this thesis it is necessary to highlight the main steps towards the evaluation of the developed analysis of local energy systems. The first chapter referred to recent developments and trends which signalize a global transition towards renewable energy sources. Recent literature predicts enormous costs concerning the energy transition process in Germany. Therefore government, economy, industry as well as society have to cooperate in order to transform the global energy system successfully. By promotion of local energy systems society has an opportunity to support the transition process.

Building up on that, chapter 2 illustrated present technologies utilized in local energy systems. The understanding of basic technical principles is the prerequisite to realize the complexity of small energy systems. After the second chapter gave explanations regarding the technical components, the third chapter summarized results of recent research which refer to technical components. By any means, it is evident that past research extensively studied energy systems on a household level. There is a large diversity of energy system modulation. Some approaches are based on numeric methods to display the technical processes within the energy system. Other modulations use forecasting methods to predict future energy supply and demand. As a result, the energy modulations of the presented studies show many strengths. Firstly, the modulation itself proves to be very precise. Every component is integrated adequately. Secondly, the study of Staudacher et al. is based on real measurement data which reflects a strong reference to reality. This enhances the applicability. Nonetheless, the presented studies come up with weaknesses. Both studies of Staudacher et al. only examine a two-component energy system. Tjaden et al. added the analysis of the combination of PVS, heat pump, water storage and battery storage but the time resolution is restricted to a 15 minutes interval. These disadvantages indicate for room of improvement.

The herewith submitted analysis of local energy systems is based on real measurement data as well as a time resolution of one minute in order to consider the strong fluctuations of PVS. As a unique feature, the analysis includes the demand of two electrical vehicles. Even though the modulation of the electrical lacks precision, it is a first step to integrate a new development into an energy system analysis. Due to the high time resolution the analysis is able to track PVS output, state of charge, discharged power, charged power and grid power in each minute over the course of the year. In addition to this, an intelligent operating concept utilizes the PVS output in the most efficient way within the system. Unfortunately, the modulation of heat and water storage also has deficits regarding the complexity. The mentioned limitations of 4.4 support these points.

After the explanation of the entire analysis, four scenarios were evaluated with respect to their performance. The results to a certain extent agree with previous research. Still, the application provided novel results regarding to Hanover. Furthermore, the addition of costs as an economical criterion expanded the comprehensive application. According to the results, small investments are more cost-efficient than investments higher than 30.000€. These results reveal a large utility for house owners. Moreover, the analysis of the 4th scenario proved the supply of electrical vehicles via PVS as a possible option. The conditions of the 4th scenario facilitate a PSS value of 75,28 %. Regarding the sensitivity analysis it is evident that maximum charge and discharge rates almost have no impact on the energy system performance. Only in the range of 1 kW to 3 kW the charge or discharge rates seem to be significant for the battery storage performance.

Since the submitted analysis of chapter 4 has been implemented via MATLAB it is expandable with other components at any time. The adequate modulation of heat pump, water storage as well as electrical vehicle would complete the analysis. Hereby a comprehensive analysis would be given which would extend the previous studies. Moreover, the implementation of an economical analysis via MATLAB would add a new criterion. As a result, the analysis would represent a strong decision support system for house owners. Moreover, the analysis could be utilized as a forecasting tool which is based on real measurement data. These aspects indicate a promising outlook. Finally, the extensive analysis of local energy systems provides results which can be abstracted to deepen the understanding of global energy systems.