Development of a Simulation Tool for Local Renewable Energy Production and Consumption

Masterarbeit

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1 Introduction to renewable energy sytems

1.1 Topic and Motivation

The recent development in the perception of environmental changes has led to differing judgment of public authorities in regard to the support for renewable energy has altered. In particular, the advantages in comparison to conventional energy resources support a strategy change to ensure a sustainable environment protection.[1] So far in 2008, the share of renewable energy supply covers about 12.9 % of the global energy demand. The main sources of energy today are coal (28.4%), gas (22.1%) and oil (34.6%) compared to nuclear energy (2.0 %).[2] The need for sustainable options to lower the shares of conventional energy supply and with this their emissions can be noticeably viewed in the changes of political and public programs in recent years. Still satisfying the increasing demand for energy, more and more of the shares should convert to the so called "renewables" in the coming years by various local solutions. One of the most promising answers to this is called decentralized renewable energy systems.

The category of renewable energy resources includes direct solar energy, ocean energy, wind energy, hydro power, geothermal energy and mainly bio energy.[3] Population growth and economic development lead to advanced technological efficiency. In the past, problems have been examined in regard to the supply of energy facing an continuous growth in energy demand.[4] Shifting to the side effects of energy supply a very important aspect is the protection of the environment. Recent examples regarding to water and maritime pollution, ambient air quality and global climate change have been grouped under the name of greenhouse effect.[5] The need to establish new strategies has improved the behavior and perception of the people to save energy on the demand side and be more efficient in energy production on the supply side. A change in application of more and more renewable energy resources could be a first step to mitigate problems for the environment and climate change.[6]

In 2000, Germany as one of the first has introduced an important step with releasing the renewable energy law (latest release EEG 2014). Since then, the integration of renewable energy resources on the market and their controlled expansion must be carefully planned. Major characteristic expressed within this law is a slow transformation in favor

[1] See Menanteau et al. (2003), p. 799.
[2] See Edenhofer et al. (2012), p.10.
[3] See Edenhofer et al. (2012), p.10.
[4] See Dincer (2000), p.158.
[5] See Dincer (2000), p.160.
[6] See Lund (2007), p.912.

of renewable over the years.[7] Ever since, a large share of electricity has been supplied from renewables, which can be quantified by 25.3% in 2013 exemplary. This corresponds to about 147 billion kWh of provided electricity. The target of the German government in 2030 is to achieve a share of 50% and in 2050 of 80% out of regenerative energy resources.[8]

In order to achieve those ambitious goals, the use of renewable energy systems has widely been discussed and applied. A detailed overview of the integration of those systems, their characteristics and usage are described in the upcoming sections. Hence, the objective of this thesis is to contribute by developing a simulation tool for local renewable energy production and consumption. This should lead to a decision support system helping to plan an calculate various dimensions before building such complex installations.

1.2 Problem explanation and Research question

The necessary conversion from conventional to renewable energy is a fundamental point within this observation. The definition of what a renewable energy really is, should therefore be determined at the very first stage. *Renewable*? The definition includes a natural source, which is continuously replenished by itself and does not run out through its usage. Additionally, sustainability as major characteristic applies and is applicable to solar energy, wind, bio energy or hydro power. Nuclear energy is not a part of this definition because of this reason. Furthermore, Germany released an energy concept 2050 prioritizing the electricity production with the help of renewable energy resources and supports the decentralized expansion of combined heat and power generation.[9] The federal concept is formulated by the Renewable Energy Research Association (FVEE) and supports a German energy supply system based on 100% regenerative energy. The main idea behind concentrates on moving away from centralized fossil power plants to decentralized renewable energy resources focused within this study. Further keywords like virtual power plants and heat storage solutions play an important role in this context. The upcoming sections 4.2.1 follow a detailed differentiation and implementation of virtual power plants. Generally seen, the concept suggests a system with 100% renewable energy usage which should be realized no later than 2050 based on remarkable technical innovation. With the help of several aspects such as energy savings, efficiency gains through E-mobility, power-heat-coupling operations and electricity production through wind or solar energy, it should be ensured to completely avoid natural gas, nuclear energy or coal.[10]

[7] See EEG (2013).
[8] See Kuhlmann et al. (2014), p.3,7.
[9] See Stadermann (2010), p.4-5.
[10] See Stadermann (2010), p.12-16.

In context of this thesis, a calculation model will be developed illustrating a decentralized energy supply for a new planned construction area. The content-related focus lies on the combination of electricity and thermal energy. In order to satisfy these respective demands, local photovoltaic modules on every roof of the buildings will be used in combination with a wind turbine, which balances the electrical demands if the solar energy is not sufficient. Thermal energy coming from a power plant, that operates with wood chips, is installed and covers the base load. However, the entire concept achieves no independence from fossil energy sources. The deficits of electrical and thermal supply at peak demands are offset by the public grid and heat network. Furthermore, it provides suggestions for the reconstruction of already consisting housing areas. With this, the devolved simulation tool evaluates the resulting profitability and costs over one year. It is possible to illustrate different scenarios by varying consumption profiles, weather conditions or legal circumstances that change the correspondent cost situation, the related energy production and consumption respectively. It is expected that raw fossil materials such as crude oil, natural gas, coal and uranium as nuclear fuel could not satisfy the demand in the future. Recent statistics show, that a rising demand will most probably not be covered for the coming decades.[11] The introduction of the EEG (2014), the development of the energy concept 2050 by Stadermann (2010) or numerous analysis about an efficient use of renewable energy resources in the future support the importance of the displayed premises.[12] The underlying research question can be defined as follows:

How can renewable energy resource systems be planned and calculated in regard to production and consumption of electrical and thermal energy, considering profitability and the respective environmental footprint?

1.3 Aim, approach and structure of this thesis

The energy concept 2050 introduces a prospected future scenario where Germany is independently managing its energy supply using renewables. By means of this thesis is a simulation tool developed which helps to evaluate the profitability and CO_2 emission of an overall energy system. It is applied using current real life data and considering technical feasibility, legal conditions and climatic effects and interprets future scenarios to proof examine developments. Furthermore, the tool applies to a municipality that utilizes a combined heat and power plant with an local heat network. This will be realistically

[11] See Andruleit et al. (2011), p.15,18.

[12] See Fais et al. (2014), Weniger et al. (2014), Saboori et al. (2011), Pudjianto et al. (2007), Menanteau et al. (2003), Lund (2007).

viewed in the dimension of thermal energy production where it is not feasible for a sole household alone.

The implementation of the model is performed with the help of MATLAB, which is a powerful programming software that evaluates and visualizes complex calculations and results in a fast but efficient way. The user interface is implemented in Excel to attain clarity of the data in input factors and to facilitate the application.

The structure of the thesis is divided into several sections which represent the conceptual framework. A visualization of the it takes place in section 4.1.1. Before, a literature review in section 2 should give an overview about the current state of research and relevant studies regarding this topic. Additionally, the methodology based on the design science research by Hevner et al. (2004) forms the basis of the examination method. The third section deals with the operation of photovoltaic systems (PV), wind turbines and combined heat and power plants (CHPP) including technical, economic and legal aspects. This section introduces thereby the used renewable energy technologies in order to get a better understanding of relevant impacts and cost calculations of the following sections. As already mentioned, the framework of the analysis is illustrated in the fourth section. Additionally, the model input parameters, that are presented in the simulation tool, are described in detail. These include a description of the PV system, wind plant and CHP as well as the model for the calculation of the thermal energy demands. The fifth section illustrates the implementation of the model into the programming software MATLAB and Excel. The user interface is described to better understand the handling of the program itself. The analysis of the data and scenarios follows in section six. That comprises the climate data and electrical and thermal consumption profiles as well as different scenarios with individual main aspects such as legal or climatic changes. The first scenario constitutes the basis including electrical and thermal energy production and consumption and a cost analysis. The second scenario deals with comprehensive evaluations of climate impacts on the thermal demands. The third scenario evaluates climate impacts on electrical demands regarding to a changing intensity of solar irradiation. The fourth scenario assesses the impacts on the cost calculations in regard to legal conditions. Finally, the thesis ends with limitations of the analysis, an outlook and a conclusion in the seventh section.

changes and to determine which alterations entail the presented consequences. There are many other applications and scenarios possible. In reality there is a constant change of more than one factor observable. Due to this, the exemplary cases should only give an image of its volatility.

7.2 Conclusion and outlook

According to the prevailing theoretical basis, this thesis has tried to support the existing efforts to enhance the understanding of renewable energy systems and their application. Conceptual deviations have been made to align the attempts of planning such complex systems looking for practical and economical feasibility. Building a comprehensive tool to combine recent theories and technical solutions has therefore been the major objective answered within the scope of this study.
The research question of how renewable energy systems can be constructed in practice and calculated in regard to the production and consumption of electrical or thermal energy can partially be answered by this thesis. A complex concept of photovoltaic systems in combination with wind turbines provides the electrical energy for a new construction area with 43 respective households in north Germany. Next to this, the thermal energy is satisfied by a combined heat and power plant that operates with wood chips. Additionally, the economic and environmental aspects are discussed and analyzed with the help of various scenarios. Hence, the results show the cost and CO_2 emission savings with a PV system that is south orientated and have an inclination angle of 45° . The 30% usage of the 330 kW wind turbine has been sufficient in this case and constitutes the optimal dimension in regard to costs and necessary electrical supply. The base load of the thermal energy has been satisfied with a combined heat and power plant that provides 73 kW of rated power. All further demands are covered by a peak load boiler. The potential thermal energy demand can be satisfied by this boiler even when a system failure of the CHP takes places. However, the scenario analysis proofs that a small proportion cannot be covered in case of a year with very cold temperatures. In this sense, additional heaters could solve this problem.
It can be summarized that dependent on the system size and its energy sources, the performance can cover the demands, be profitable and could contribute to the environmental protection. It illustrates a practical approach for further research in order to process complex energy concepts facing the German objectives of expanding renewable energy coverage up to 80% until 2050.

This forward-looking is fundamental in order to establish an enhanced attractiveness for renewable solutions. Legal support for example based on the EEG (2014) even supports

to sell the surplus of own produced electrical energy. Furthermore, in regard to wind turbines and photovoltaic systems, further cost reductions are expected. The growing size of wind turbines entail better energy performances due to rising wind speeds at higher hub heights. Otherwise, the available locations for turbines run short and lead to the trend of moving the production sites to less windy areas. On the other side, the enhancement of the photovoltaic modules with new materials and better efficiency lead to reduced costs.[91] Future research should focus on more efficient technologies since their combinations achieve large advantages where more and more independence from fossil energy resources takes place. Additionally, the focus in order to ensure grid stability should become increasingly important because of changing network utilization.

[91] See Quaschning (2013), p.388.