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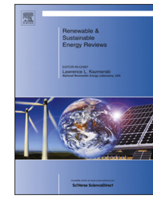

A comprehensive model for the German electricity and heat sector in a future energy system with a dominant contribution from renewable energy technologies – Part II: Results

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ABSTRACT

A clear consensus exists in German society that renewable energy resources have to play a dominant role in the future German energy supply system. However, many questions are still under discussion; for instance the relevance of the different technologies such as photovoltaic systems and wind energy converters installed offshore in the North Sea and the Baltic Sea. Concerns also exist about the cost of a future energy system mainly based on renewable energy. In the work presented here we tried to answer some of those questions. Guiding questions for this study were: (1) is it possible to meet the German energy demand with 100% renewable energy, considering the available technical potential of the main renewable energy resources? (2) what is the overall annual cost of such an energy system once it has been implemented? (3) what is the best combination of renewable energy converters, storage units, energy converters and energy-saving measures? In order to answer these questions, we carried out many simulation calculations using REMod-D, a model we developed for this purpose. This model is described in Part I of this publication. To date this model covers only part of the energy system, namely the electricity and heat sectors, which correspond to about 62% of Germany's current energy demand. The main findings of our work indicate that it is possible to meet the total electricity and heat demand (space heating, hot water) of the entire building sector with 100% renewable energy within the given technical limits. This is based on the assumption that the heat demand of the building sector is significantly reduced by at least 60% or more compared to today's demand. Another major result of our analysis shows that – once the transformation of the energy system has been completed – supplying electricity and heat only from renewables is no more expensive than the existing energy supply.

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1. Introduction

The current discussion on how or even whether we should transform our fossil-fuel based energy system to a renewable system is often based on emotions rather than facts. Political instruments like the German Act for Renewable Energy Technologies "Erneuerbare-Energien-Gesetz" (EEG) are very controversial. Discussions are carried out about the number or the kind of power plants needed, the dimensioning of storage and the expansion of the electricity or district heating grids. In this paper, we aim to assess these issues by drawing on numbers and assumptions from different reliable sources and applying a complex computer model that calculates hourly energy balances for the interaction between the German electricity and heat sectors. The assumptions and the methodology of our REMod-D model were introduced in the first part of this two-paper series [1]. In the present paper, we consider different scenarios in which the energy demand for space heating, hot water and electricity is satisfied with 100% renewable energy resources.[1] We investigate different system configurations, the influence of importing electricity on the system dimensioning, the consequence of keeping a certain proportion of fossil fuels in the system and the importance of energy retrofit measures in the building sector.

2. Constrained potential

The location of Germany inherently causes limitations on the production of electricity and heat from renewable energy sources. Due to limiting factors like required area, average wind velocity or available solar radiation intensity, the availability of renewable energy resources at any time is finite. What these limitations for Germany are and how they restrict the energy system will be discussed in the following paragraphs.

2.1. Wind turbines

To calculate the theoretical installable capacity of wind turbines in a certain country, both the availability and especially the useable area have to be evaluated. The number of wind turbines that can be built on this area depends on the separation needed between two turbines. This distance is necessary to guarantee good wind conditions for each turbine, so that the efficiency of converting wind into electricity is not affected. This theoretical potential is then reduced because of different social, environmental, economic or political restrictions. Due to the wide diversity of influences, we will mention only the most important ones (more factors are specified e.g. in [4]). Economic viability has the greatest influence on the decision as to whether a wind turbine should be built or not. If a turbine is installed in a location with little wind, such as in wind shadows or rough terrain, the efficiency decreases and the amount of produced electricity, and thus revenue, diminish. In addition, with increasing distance from the coast, the total cost of offshore wind turbines increases due to longer grid connection distances and especially due to higher expense for constructing turbines in deeper water.

Besides these technical restrictions, the so-called "soft factors" also strongly influence the potential of renewable energy technologies. For example, there are restrictions for offshore wind turbines such as the distance to the coast due to esthetic reasons, military areas, trade routes or environmental restrictions such as bird sanctuaries. Also laws that regulate the distance of turbines from housing areas can restrict the number of installed onshore wind turbines. Within this study, we use the constrained potential determined in the Windenergiereport Deutschland (2011) published by Fraunhofer IWES [5]. The values given are 200 GW_{el} and 85 GW_{el} for wind onshore and offshore, respectively.

2.2. Solar thermal collectors and photovoltaics

In a further study published by Fraunhofer IWES [6], the constrained potential of areas for solar thermal or photovoltaic facilities is calculated. These areas result from theoretically available areas that are reduced due to specific limiting factors. The economic viability is technically constrained mainly because of differences in the intensity of solar radiation. It is, for instance, not reasonable to install solar collectors on north-facing surfaces, be they roofs, railway embankments, highway sound barriers or facades. On open land, it is possible to choose the perfect orientation, but these areas are usually in high demand and competition exists with other forms of land usage such as agriculture or nature conservation areas. Fig. 2.1 shows the values obtained in the Fraunhofer IWES study. In total, there is a viably useful area of 2845 km² (excluding open land areas[2]), which is equivalent to an installed capacity of about 2000 GW_{th} of solar thermal collectors or an installed capacity of 400 GW_{el} of photovoltaic systems or, of course, a combination of both technologies.

2.3. Hydropower

In contrast to the technologies mentioned above, the installable potential for hydropower facilities in Germany is relatively small. Therefore this technology is not included within the optimization process of the model and the values are fixed (cf. [1]). The capacity of installed run-of-river installations is fixed at 5 GW_{el} and the amount of electricity generation is limited to 21 TWh. These values are slightly higher than today's values. In 2007, the installed capacity of run-of-river power plants in Germany was 4.3 GW_{el}

[1] In comparison, the energy supply for domestic heat and hot water in Germany in 2010 was mainly based on fossil fuels (oil 25%, natural gas 47%, coal 2%) and was based only to a small extent on renewable energy (12%), district heat (10%) and electricity (4%) [2]. The electricity production in 2010 was based on about 86% fossil fuels and nuclear power and the rest was based on renewable energy sources [3].

[2] We do not include the possible useful area of open space due to the great uncertainty concerning future use of these areas.

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