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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 I: Methodology

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ABSTRACT

A clear consensus exists in the German society that renewable energies 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. Also concerns exist about the cost of a future energy system mainly based on renewable energies. In order to be able to address the raised issues on a scientifically sound basis we have set up a new simulation model REMod-D (Renewable Energy Model-Deutschland) that models the energy balance of the electricity and heat sector including all renewable energy converters, storage components and loads for a future German energy system for a whole year based on an hourly energy balance. The target energy systems modeled use a high fraction up to 100% of renewable energies to cover the electricity and heat demand (heating and hot water). The model includes also energy retrofit of buildings as a measure to reduce future heat loads of the building sector. A mathematical–numerical optimizer is applied in order to identify system configurations with minimal overall annual cost. In this first part of a two-paper series we describe the methodology of the REMod-D model and discuss cost and performance values of all included components and in the second part we will discuss the results.

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1. Introduction

In the summer of 2011 the German parliament approved new ambitious targets for the transformation of the German energy system. A key strategy towards this transformation mandates a planned continuous increase in electricity from renewable energy sources: the fraction of total electricity supply from renewable energy sources shall increase to 80% in 2050 (35% in 2020; 50% in 2030; 65% in 2040, respectively).[1] Second it was decided to reduce Germany's primary energy demand to 80%, as compared to 2008 values, by 2020 and to 50% by 2050 [1]. In addition Germany supports the EU objective of reducing greenhouse gas emissions by 80–95% by 2050 compared to 1990 [2]. While the long-term targets are clearly defined, significant uncertainty still exists on which paths to take to achieve these targets as well as on what is the optimal mix on the generation, conversion and demand side. However, there is almost no doubt that energy savings on the demand side, energy efficiency in conversion chains and a large fraction of energy generated from renewable sources on the production side are the key elements for achieving these long-term goals.

In this paper we describe REMod-D (Renewable Energy Model-Deutschland), a newly developed model which performs a systematic optimization on two main sectors of the German energy system, namely the electricity sector and the heat sector, focusing on a future energy system characterized by a high renewable energy fraction. In a second paper we present and analyze results of the simulations carried out with the model described here [3]. Together the electricity and heat sectors cover about 53% of the final energy demand and are responsible for about 62% of the primary energy consumption (see Section 2). For the model development these two sectors were chosen for the following reasons:

- There is an increasingly strong link between the electricity sector and the heat sector: on the one hand an increasing number of electric heat pump systems are used for heating buildings and on the other hand an increasing number of combined heat and power systems (CHP) in a wide range of capacities is employed.
- Energy-saving building retrofit measures are considered to be a key element in increasing energy efficiency and as such it is included into the model.
- The sectors not covered by the model are fuel based energy consumption in the mobility sector (private cars, trucks, air transportation) and the industry. The long-term future of the fossil-fuel based mobility sector is uncertain under today's perspective. Various trends are visible and discussed. These include battery-powered cars, hydrogen-powered cars using fuel cell technology, trucks employing centralized electricity using trolley bus technology and many other concepts. A wide diversity exists today with regard to using fossil fuels in industrial processes. Many processes are available which have very different boundary conditions and varying potentials for efficiency measures at a variety of costs. Therefore, the mobility and industrial processing sectors remain more difficult to implement into a coherent energy-economic model based on hourly energy balance calculations as used in our model. As of now, they are left out of the model discussed here. However, their effect on the overall German energy balance is considered in Section 2 and briefly discussed again in the second part of this paper [3].

Various simulation models for national energy systems, which consider a high penetration of renewable energies, exist, but only a few models are able to combine the supply and demand from both the electricity and heat sectors. Many of the energy system models developed in the past focus on the electricity sector and its development but rather neglect the heat sector or do not cover it in detail. For example, the BALMOREL or the SIVAEL model cover the electricity sector but only district heating for the heating sector [4]. The EMCAS model focuses in detail on the operation of power systems [5]. A widely used example that covers both the electricity and the heat sector is the EnergyPLAN model developed in Denmark which has been applied to a number of different scenarios and regions [6–12]. The EnergyPLAN model calculates an optimal system configuration regarding heat production from solar thermal collectors, industrial CHP, decentralized and

[1] Bundesgesetzblatt No. 42, August 4th, 2011, Page 1634 http://www.bundesregierung.de/Content/DE/Artikel/2011/08/2011-08-05-gesetze-energiewende.html.