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Assessment of transformation strategies for the German power sector under the uncertainty of demand development and technology availability

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ABSTRACT

The long-term energy strategy issued by the German government in 2010 and 2011 embraces a substantial reduction of CO_2 emissions and high shares of renewable energy in electricity production, along with energy efficiency improvements and an accelerated nuclear phase-out. While several studies illustrate scenarios reaching these targets, there are substantial uncertainties pertaining to key assumptions, particularly long-term electricity demand and the large-scale availability of offshore wind and carbon capture and storage (CCS). This paper explores conditions under which model-based scenarios for the German electricity sector comply with the official targets for CO_2 emission reductions and renewable shares. We apply the energy system model LIMES-D, which allows for a joint optimization of generation and transmission capacities. The results indicate that reducing electricity demand plays a crucial role for attaining the government's targets. Scenarios for which either offshore wind or CCS is not available show an even stronger need for a decreasing electricity demand to reach the targets and a different pattern of transmission capacity expansion than is the case with full technology availability. Hence, a broad technology portfolio could in turn hedge against future power demand increases that may challenge the joint attainment of the German decarbonization and renewable energy targets.

Contents

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1. Introduction

The German government set ambitious long-term targets for CO_2 emission reductions, energy generation from renewable energy technologies and energy efficiency improvements in its energy concept [1]. In the year 2011 it was amended so as to include the accelerated phase out of nuclear power decided upon in the aftermath of the events in Fukushima Daiichi [2]. The energy concept embraces a profound restructuring of the German energy system, known internationally as the German “Energiewende” (energy transition). Until the year 2050, CO_2 emissions are intended to decrease by 80–95% relative to 2005, the share of renewables in electricity production shall increase gradually to at least 80%, and total electricity demand is meant to decrease by 20%.

Even though the “Energiewende” addresses all sectors of the energy system, the plans for the electricity sector are most concrete and it has developed most dynamically in the recent years: over the last decade, the share of renewables in electricity generation increased by more than 15 percentage points to 23.5% in 2012 [3]). Also, the renewable energy target in the electricity sector is the only one that is legally binding, as it is explicitly specified in Section 1 of the Renewable Energy Act [4]. Considering that the climate and energy policy targets for CO_2 mitigation, high shares of renewables and electricity demand reduction are not independent of each other, the following questions arise: What are the conditions under which these interacting targets can be reached jointly? Which low carbon technologies are particularly important in this context?

While there are many sources of uncertainty in the development of long-term scenarios for the German power sector, two issues are particularly important in the present context: the future development of electricity demand and the large-scale availability of innovative low-carbon technologies, particularly offshore wind and Carbon Capture and Storage (CCS). When taking into account statistics for the last ten years, electricity demand has been constant or rising and strongly connected to economic developments [5,6]. While extensive energy efficiency measures could lead to significant reductions in aggregate demand, current trends do not indicate that a rapid acceleration of energy efficiency measures will occur in the near-term future. Also, it is unclear whether postulated energy efficiency potentials can after all be leveraged in Germany [7]. Furthermore, since future electricity demand might increase e.g. due to extensive electrification of other sectors such as transport, no unambiguous projection for electricity demand is available.

Regarding the second issue, technology availability, it is widely acknowledged that technologies drawing on solar and wind energy will play a substantial role in the future German power generation mix [see e.g. [7]]. In the past decade many gigawatts of solar photovoltaic (PV) and wind onshore capacities have been installed and these technologies have proven their large-scale viability. However, in the case of offshore wind the development has been very sluggish, owing to numerous engineering, legal, and logistical challenges [8]. Also, the availability of CCS on a commercial scale in Germany is highly uncertain [see e.g. [9]] and is subject to decisive opposition by local communities and only limited political support. Yet, the various available long-term scenarios for the German power sector postulate the large-scale availability of offshore wind and CCS [e.g. [10,11]] in the near-term future.

This paper explores the impacts of different conceivable assumptions regarding the development of electricity demand and technology availability in the German electricity sector on the compliance of model-based mitigation scenarios with the German government's long-term climate and energy policy targets and the system-cost optimal technology portfolios. We thereby apply a German version of the Long-term Investment Model for the Electricity Sector LIMES [12–14], referred to as LIMES-D hereafter. It allows not only for a joint inter-temporal optimization of long-term generation and transmission capacity deployment while accounting for effects of investments with perfect foresight, but also takes into account the impacts of short-term fluctuations arising from wind and solar utilization. This paper contributes to the existing literature by revealing important interdependencies of generation and transmission capacity planning for the German electricity sector that, due to the absence of a suitable energy system model for Germany, have not been made explicit in scenario analyses to date.

The remainder of this article is structured as follows: Section 2 discusses the setup of models used for previous scenarios of the German power sector, showing that to date no integrated analysis that jointly optimizes transmission and generation capacity deployment has been pursued. Section 3 presents relevant features of the model LIMES-D (Section 3.1) and the setup of the different scenarios for this analysis (Section 3.2). While Section 4 illustrates the scenario results, Section 5 briefly compares them to other studies. Finally, Section 6 discusses the findings of this research and concludes.

2. Literature review

So far, integrated assessments of the combined requirements for an adequate grid in Germany together with the necessary expansion of generation capacities have received only little attention. Several analyses have been published recently, but none of the studies is developed with a model that is capable of taking into account the interplay between generation and transmission capacity planning endogenously. The common practice is to either focus on generation capacity planning and postulating Germany was a copper plate, or to adopt a clear focus on transmission grids and take generation capacity development as an exogenous assumption over the entire time horizon of analysis.

Table 1 illustrates this observation. It presents a review of recent studies and different models used for investigating the German power system and its transformation and checks temporal and spatial resolution, power grid representation and the development of power generation and transmission capacities within the respective model or study. Literature summarized in Table 1 can be subdivided into four categories (visualized by horizontal lines). First, studies commissioned by the German policymaker or other political actors that present scenarios illustrating how Germany can successfully achieve the “Energiewende”. Second, integrated assessment and energy system models for Germany that have a clear focus on the intertemporal dynamics and economic impacts of generation capacity deployment. Third, models that have a very fine resolution of the power grid enabling dedicated analysis of transmission capacity planning for Germany. A fourth category covers recent integrated energy system models investigating both transmission and generation for Germany or Europe, to which the model applied in this study – LIMES-D – also belongs to.

The comprehensive scenario studies investigating the development of the German power sector mainly cover generation technologies and treat infrastructure network issues only briefly [11,10,15–17]. Several models have been used in the past for the investigation of energy scenarios for Germany [18–21]; however, most of them focus on the energy system as a whole and either omit spatial consideration of power transmission or use rough approximations. Others, such as German Energy Agency [23], Leuthold et al. [24], Weigt et al. [28], Leuthold et al. [29], Weigt