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Renewable energy sources in European energy supply and interactions with emission trading

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ABSTRACT

This paper presents a model-based approach, which allows to determine the optimised structure and operation of the EU-15 electricity supply under different political and economic framework conditions, with a focus on the integration of renewable energy sources for electricity generation (RES-E) in the EU-15 countries. The approach is designed to take into account the characteristics of power production from both renewable and conventional sources, including the technological and economic characteristics of existing plants as well as those of future capacity expansion options. Beyond that, fuel supply structures are modelled, as well as the international markets for power and CO_2-certificates with their restrictions. Thus, a profound evaluation of the exploitation of mid-term renewable potentials and an assessment of the market penetration of the various renewable power generation technologies under the (normative) premise of a cost-optimised evolution of the power system becomes possible. Results show that a promotion of renewable energies reduces the scarcity of CO_2-emission allowances and thus lowers marginal costs of CO_2 reduction up to 30% in 2030. Despite the higher overall costs, a diversification of the energy resource base by RES-E use is observed, as primarily natural gas and nuclear fuels are replaced.

1. Introduction

Along with efforts to achieve CO_2 mitigation and a better energy efficiency, one major contemporary strategic challenge for the European electricity supply system is the integration of substantial amounts of renewable energy sources. In addition to the specific goals for each EU Member State already set in Directive 2001/77/EC for 2010 (Commission of the European Communities, 2001), more ambitious targets have been set for the share of renewable sources in final energy consumption (not only electricity) for 2020 in the Directive 2009/28/EC (Commission of the European Communities, 2009).[1]

While the performance parameters of renewable energy technologies are continuously being improved, the politically and environmentally motivated introduction of significant amounts of renewable electricity generation is likely to depend on incentive schemes in the short- to mid-term future. Besides the inhomogenous geographical distribution of renewable energy resources, the temporal evolution of renewable electricity market penetration in the EU Member States will thus be influenced by the different design options for national promotion schemes and their possible future harmonisation.

Likewise, the future cost structure of conventional electricity generation also has an influence on the economy of renewable electricity generation and the necessary support. Moreover, physical interdependencies between renewable and conventional power generation exist. In order to develop adequate policies and strategies, policy makers as well as decision makers in utilities must be able to consider the above mentioned interdependencies in order to get an idea of the future consequences of their decisions.

In this paper a modelling approach will be presented which enables a quantitative assessment of the long-term role of renewable electricity production under varying framework conditions within the liberalised European electricity market. At first, methodological aspects of RES-E integration will be briefly introduced in Section 2. Subsequently, the chosen modelling approach will be shortly described in Section 3. The focus of this

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[1] These targets have been set for the share of energy from renewable sources in gross final consumption of energy, but no specific targets have been set for the share of electricity from renewables. However, member states are obliged to set up national allocation plans for renewable energies, where the amount of energy coming from renewable sources has to be distinguished for the transport, electricity, heat and cooling sector (see Commission of the European Communities, 2009).

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paper is set on the evolution of renewable energy production and its cost effects in European electricity supply, which will be presented for selected scenarios in Section 4. The paper ends with a conclusion and outlook.

2. Methodological aspects of RES-E integration

In most existing energy system models,[2] renewable power production and the associated energy potentials are commonly not part of the optimisation, i.e. the use of available renewable resources is not handled as an endogenous variable in the models, but introduced exogenously as a predetermined expansion path. One of the reasons for this practice is that the representation of individual RES-E potentials and their costs requires comparatively extensive efforts in terms of modelling and data gathering. Due to the hitherto low penetration and the minor relevance for the electricity sector as a whole, these efforts were worth-while only to a limited extent, as for low expansion rates the resulting bias in the model are small in relation to the whole power sector. However, the currently observed and politically fostered increase of the penetration of renewable energy carriers with growing shares of fluctuating generation makes a more appropriate representation of renewable power production in energy sector planning models desirable. Further, in order to assess the effects of renewable electricity promotion instruments adequately, these also need to be integrated into the existing modelling approaches.

While some approaches exist, which focus on the composition of the renewable part of the mix and take into account the available dynamic potentials and incentive mechanisms, these are mainly based on static merit order curves for conventional power production. Mostly, the approaches rely on market simulations, which are based on the balancing of supply and demand curves. While the supply curves on the one hand can be derived from the available potentials of individual renewable electricity generation options and their costs, the demand for renewable electricity on the other hand is determined from the electricity price and the price incentives given by the incentive schemes. Partly, the approaches are dynamic and take into account inter-temporal relations, as e.g. the evolution of incentive schemes or cost decreases as a result of learning effects. In the following, some of these dedicated approaches will shortly be introduced and outlined. One example for a dynamic simulation of the renewable electricity market in the EU is the Admire Rebus model (cf. Uyterlinde et al., 2003). Its approach is based on the static simulation methodologies of the REBUS[3] (Voogt et al., 2001) and ElGreen (Haas et al., 2001) models. Both REBUS and ElGreen use national static marginal supply cost curves to simulate an ideal TGC market. These curves indicate the correlation between the price of electricity and the amount of electricity produced from a given source and are derived from estimates of different RES-E potentials, their costs and expected performance. A similar approach as in ADMIRE REBUS is used in the Green-X model (Huber et al., 2004) and the GreenNet model (Obersteiner et al., 2006). As the ADMIRE REBUS model, these models take into account fully dynamic cost-resource curves, i.e. the potential and the cost of each renewable energy technology are determined endogenously in the model, depending on the one hand on the static cost-resource curves, and on the other hand on the outcome of the previously simulated year as well as the policy framework conditions set for the simulation year. In the case of the GreenNet model, special regard is given to the costs for the grid integration of renewable energy sources and various scenarios for their allocation.

All these models have in common that the electricity commodity price development is an exogenous model input,[4] which can be varied in scenarios. Seasonal load profiles, the international electricity exchange and its interrelation with the ETS are usually not taken into account. Similar limitations apply to the modelling of interactions of large shares of fluctuating RES-E use with conventional electricity generation. Modelling approaches explicitly focussing on these interactions usually comprise a shorter time horizon with a high temporal resolution, but without regarding inter-temporal and inter-regional aspects in the optimisation of the capacity and production mix.

Furthermore, many of the described model-based simulation or optimisation approaches, even those explicitly developed for a detailed analysis of renewable electricity evolution, neglect the interactions with conventional power production. While this is acceptable for low shares of fluctuating renewable electricity generation, these interactions become more and more significant at higher penetration rates. For those approaches that explicitly investigate the interaction of fluctuating wind power feed-in with conventional electricity generation[5] it can be argued[6] that they often merely consider the absorption of wind power in today's base load dominated electricity systems. As the system structure will not be static in the medium to long term, this results in a biased view of the effects in the conventional power system.

Consequently, the developed hybrid modelling approach introduced in the following aims at combining the relevant long-term and short-term aspects of conventional and renewable power generation as well as their interactions on different time scales. This hybrid modelling approach consists of the optimising long-term energy system model PERSEUS-RES-E (Rosen, 2007) and the heuristic model Aeolius (Rosen et al., 2007) for the temporally highly resolved simulation of the scheduling of conventional power plants with growing fluctuating wind energy feed-in.

3. Long-term energy system model

3.1. Outline of the developed modelling approach

The general objective of the energy system model PERSEUS-RES-E is to provide an analysis tool for the quantification of the economic and technological impacts that the policy framework of the required utilisation of renewable sources for

[2] There exist several well-known models of the long term development of energy markets, such as MARKAL (Market Allocation Model, Fishbone and Abilock, 1981), PRIMES (Capros et al., 1998; Antoniou and Capros, 1999), EFOM (Energy Flow Optimisation Model, Finon, 1974; Van der Voort et al., 1984), MESSAGE (Model for Energy Supply System Alternatives and their General Environmental Impact, Agnew et al., 1979; Messner and Schrattenholzer, 2000), TIMES (The Integrated MARKAL EFOM System, Remme, 2006) and NEMS (National Energy Modelling System, Department of Energy (DOE), 2008). However, these models are in general able to include renewable energy potentials (see e.g. Remme, 2006), but detailed analyses dealing with renewable energies covering EU15 are unknown to the authors. Besides that, it has to be pointed out that most of the above mentioned models are energy system models (covering different energy sectors) and in opposite to that PERSEUS-RES-E focus only on the electricity sector. A more detailed overview about models analysing European energy markets can be found in (Möst and Perlwitz, 2009).

[3] **R**enewable **E**lectricity **BU**rden **S**haring.

[4] In the case of the GreenNet model, the exogenously given price development results from a stochastic fundamental electricity market model.

[5] There exist several approaches which investigate the interaction of fluctuating wind power feed-in with conventional electricity generation. At this point, we refrain from giving a detailed overview about such models and refer to the following literature dealing with such models: Leonhard and Müller (2002), Fischedick (1996), Lux (1999), Krämer (2003), Lux (1999), Sontow (2000), Dany (2000), Dena (2005), Holttinen (2004) and Brand et al. (2005).

[6] This argumentation is e.g. also brought forward by Krämer (2003).