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On integrating large shares of variable renewables into the electricity system

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ABSTRACT

In recent years increasing shares of variable RES (renewable energy sources) have changed the structure of electricity markets in Western Europe, especially in Germany. The core objective of this paper is to provide insights on the conditions to integrate even larger quantities of variable RES into the electricity system by using market-based principles and how, straightforward, a sustainable electricity system could work. Our major finding is that we suggest a market-based approach to ensure that competitive forces rather than governmental interferences as capacity mechanisms shape the future of the energy system. The major conclusions of this analysis are: The transition towards a competitive and sustainable future electricity system will be based on an approach of "new thinking" which is to accept a paradigm shift in the whole electricity system. This includes switching to a more flexible and smarter system allowing a greater scope for demand participation, storage options and other flexibility measures. Developing such a system implies also that no politically motivated capacity mechanisms are needed.

1. Introduction

The European Commission has set ambitious targets for increasing the share of electricity from RES (renewable energy sources), e.g. Ref. [1]. In recent years in the EU-28 countries electricity generation from variable sources like wind and solar has increased remarkably, with Germany, Spain, Italy leading. Between 1997 and 2014 in the EU-28 "new" renewables excluding hydro grew from less than 1% to about 13%, mainly from wind, see Fig. 1. In addition, the EU has set further ambitious targets of a share of 27% (compared to about 14% in 2013) energy from RES by 2030. This target is for all uses, heat, electricity and transport. Consequently, also electricity generation from RES will grow further continuously, as documented in the NREAPs (*National Renewable Energy Action Plans*) despite it is not clear to which absolute level. The major motivation for this paper is to show what is needed for integrating these higher quantities into the electricity system.

The increasing shares of variable RES have especially in Germany changed the usual pattern of electricity markets in Western Europe. Yet, variable RES-E do not provide electricity simultaneously with demand. It is important to note, that almost all other generation technologies do not either. The fact that these must run capacities are offered at Zero costs over a large time per year have led to the argumentation that fossil plants like CCGT (Combined-cycled gas turbines) or coal power stations become economically less attractive because of the lower full load hours per year. This argument has led to the call for CM (capacity mechanisms) in addition to the current "energy-only" markets. The idea is that specific owners of a flexible power plant should be paid for holding the plant ready for operation.

Due to these developments, currently, the whole electricity system is at a crucial crossing. On the one hand, the way to a sustainable electricity system based mainly on RES could be paved in the next years. In this context we emphasize especially the considerable price decreases of PV which has brought this technology close to cost-effectiveness on household level, see Refs. [2,3]. On the other hand, there are forces which try to retain the old centralized fossil and nuclear-based generation planned economies. Centralized capacity payments (e.g. in France and England) should help to freeze this anachronistic pattern. A good survey on CM is provided in Ref. [4]. Also the EU has recognized this problem, see e.g. Koch [5] for an early contribution and Ref. [6] for a recent analysis.

The core objective of this paper is to provide insights how to integrate large quantities of variable RES-E into the electricity system by using market-based principles and how, straightforward, a sustainable electricity system could work. This market-based

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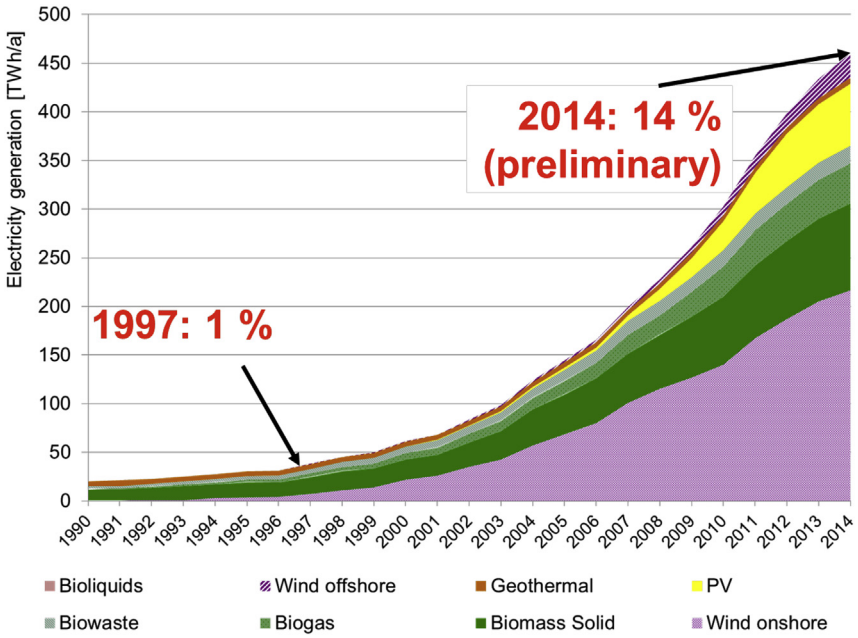

Fig. 1. Development of electricity from "New" renewables (excluding hydro) in EU-28 between 1990 and 2014, in TWh (Source: EUROSTAT, own estimations, numbers for 2014 are preliminary).

approach should ensure that competitive forces rather governmental interferences shape the future of the energy system and that in principle no comprehensive CM are necessary, see e.g. Ref. [6]. Our analysis is mainly based on Western European countries using data from Germany and Austria but in principle the findings of this analysis cam also be transformed to every other country. It builds on basics described in Ref. [2] and extends this paper towards variable renewables in general.

Regarding the state-of-the-art this work is based on the following general contributions on the topic. Major contributions for understanding the basic principles how to integrate large shares of variable RES into the electricity system are [7–13]. Analyses with special focus on the system integration of wind has been conducted by Refs. [8,14–16]. Major country specific investigations has been done for Denmark, Spain and China in Refs. [17,14,18].

A seminal contribution on flexible options in the electricity system has been conducted by Ref. [19]. Lund [20] provides the so far most comprehensive review of energy system flexibility measures to enable high levels of variable renewable electricity.

The major novelty of this paper is that it brings together all important aspects for heading towards a sustainable as well as competitive future electricity system. It considers technical options and aspects of market design and applies it to a further increase of RES in the electricity system. It addresses economic as well as technical/structural issues of electricity supply and demand. Moreover, up to the best of our knowledge it is the first one that links the concept of residual load to price signals from the wholesale markets, the relevance of flexibility measures on the demand-side as well as demand response due to these price signals and the role of storage, power-to-heat. Finally future requirements for competitive electricity market design including the political dimension of CM under the condition of large shares of variable RES in the electricity system are investigated.

2. Method of approach: how prices in electricity markets come about

To analyze the impact of variable RES on the prices in wholesale electricity markets it is first important to understand the current market rules and market structures, see Ref. [2]. Of key relevance is to understand how prices in European electricity markets currently come about. In this context it is important to look at the historical dynamics. The liberalization process in Europe started in the late 1980s in the UK and gradually migrated to continental Europe with the 1999 the EU-directive [21,26]. One of the major features of the liberalized electricity markets was that the pricing regimes changed. In former regulated markets, prices were established by setting a regulated tariff, which was calculated by dividing the total costs of supplying service by the number of kWhs sold – with some differences between different groups of customers. The major change that took place after the liberalization was that prices were now expected to reflect the marginal costs of electricity generation (e.g., [6,22–24]). Since then the price formation is mainly based on

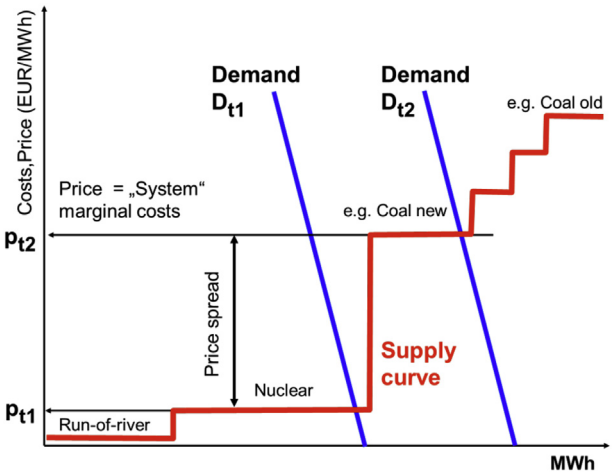

Fig. 2. How prices come about in markets with a conventional merit order supply curve based on short-term marginal costs with conventional capacities (incl. large run-of-river hydro): intersection of supply curve and demand gives electricity price at two different points-of-time.

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