HEADING TOWARDS CLEAN, SUSTAINABLE AND COMPETITIVE ELECTRICITY SYSTEMS

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ABSTRACT

Electricity generation from variable sources like wind and solar has virtually skyrocketed In recent years in the EU-28 countries. These increasing shares of variable RES have changed the usual pattern of electricity markets in Western Europe. The core intention of this paper is to serve as a primer for introducing clean, sustainable and competitive electricity markets in every country world-wide. It is triggered by the current discussion on how to integrate large shares of variable RES but the basic intention goes beyond that. It is to show how to head towards real competition in electricity systems, including all dimensions such as generation storage, but especially the customer side. The major objective of this paper is to analyze and provide insights on the conditions that will bring about a sustainable and competitive electricity system with higher shares of RES without escalating political interventions.

1. INTRODUCTION

The Paris agreements on limiting Global Warming lead to the need of higher shares of renewable energy sources (RES) in the electricity system. The European Commission has set ambitious targets for increasing the share of electricity from RES already earlier, [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 2016 in the EU-28 "new" renewables excluding hydro grew from less than 1% to about 13%, mainly from wind in the EU-28 "new" renewables excluding hydro grew from less than 1% to about 18%, mainly from phortovoltaics, biomass and 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 *National Renewable Energy Action Plans* (NREAPs) 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, see also [4].

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 simultanously with demand. It is important to note, that almost all other generation technologies do not either. The core intention of this paper is to serve as a primer for introducing clean, sustainable and competitive electricity markets in every country world-wide. It is triggered by the current discussion on how to integrate large shares of variable RES but the basic intention goes beyond that. It is to show how to head towards real competition in electricity systems, including all dimensions such as generation storage, but especially the customer side.

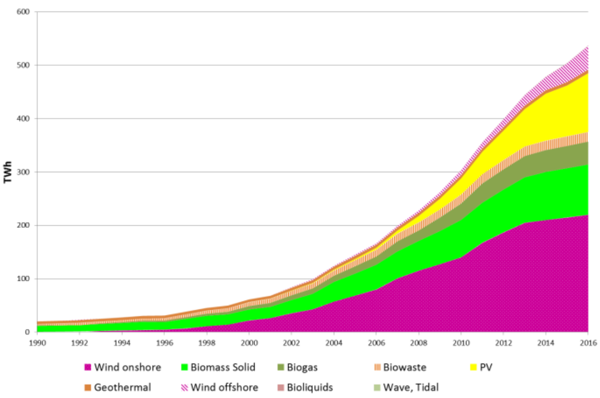

Fig. 1. Development of electricity from "New" renewables (excluding hydro) in EU-28 between 1990-2016, in TWh (Source: EUROSTAT, own estimations, numbers for 2016 are preliminary)

The major objective of this paper is to analyze and provide insights on the conditions that will bring about a sustainable and competitive electricity system with higher shares of RES without escalating political interventions. How can the original idea of competition be reestablished so that “Markets should do their work”? The objectives in detail are: (i) to explain how in the future a really competitive market-based electricity system without continuing governmental interferences can be brought about; (ii) to argue why capacity payments will not contribute to such a system but rather retain the conventional system; (iii) to show that generators will no longer be the heart of the system but rather balancing groups / supply companies.

2. METHOD OF APPROACH

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 [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 by 1999 [21]. 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., [4], [6]). Since then the price formation is mainly based on a fundamental approach where the intersection of a merit order curve on the supply-side and the demand curves results in the corresponding market price at every point-of-time, see [2] and Fig. 2. The typical historical pattern of electricity generation in the Western Central European electricity market consisted since decades of conventional fossil, nuclear and hydro capacities. Since the late 1990s in western central Europe, most of the time nuclear contributed the largest share, followed by fossil and hydro. Non-hydro renewables were not a significant factor until recently. At the time when liberalization started huge already depreciated excess capacities existed in Europe. This led to the expectation that prices will (always) reflect the short-term marginal costs (STMC) as illustrated in Fig. 2.

As shown in Fig 2, the intersection of the supply curve with demand determines the market clearing price at the price at the short-term marginal costs of the system. The curve D_{t1} shows the demand curve at times of low demand e.g., at night and p_{t1} is the resulting (low) electricity price. D_{t2} shows high demand times, e.g., at noon, and p_{t2} is the resulting (high) electricity price. The difference between p_{t2} and p_{t1} is the so-called price spread further described below. It provides useful information, for example, on the economic attractiveness of storage, which will be of high relevance in markets with large share of RES. Until recently, the price spread has been of interest mainly with respect to pumped storage. That is to say, during periods when prices are low, water can be pumped into reservoirs; while generating electricity when the opposite is true.

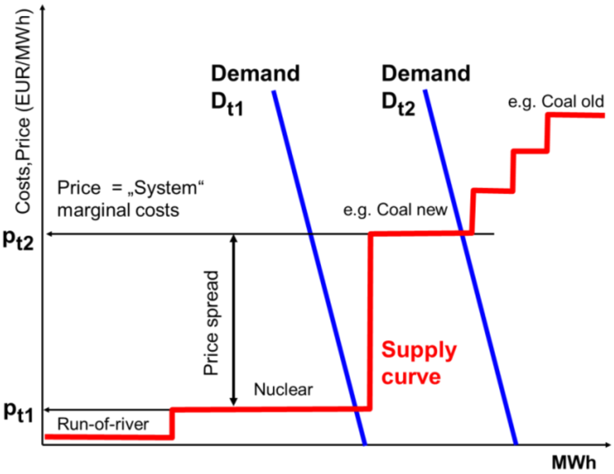

Fig 2. How prices come about in electricity markets with a merit order supply curve based on short-term marginal costs: intersection of supply and demand gives electricity price at two different points-of-time

This fundamental approach of price formation has led to quite different price developments in different European electricity sub-markets from 2000-2016, see Fig. 3. In this period a high volatility and considerable differences of electricity spot market prices between different sub-markets are observed. Within this period Italy always faced the highest prices due to its over-reliance on imported electricity, congested cross-border transmission lines and heavy reliance on expensive natural gas. In the case of the NORDPOOL, which includes Sweden, Norway, Finland, and portions of Denmark, the pattern is different due to heavy reliance on hydro and lack of strong interconnection with Continental Europe. Yet, the other countries illustrated in Fig. 4 show a remarkable convergence of prices. Currently, there is a wide-integrated Western-Central European electricity market which consists (at least) of Germany, France, The Netherlands, Austria, Switzerland, Poland, Czech Republic. That is to say that any measure in one of these countries will affect the market structure in others. Regarding the magnitude of prices the reason for high prices in 2008 in Continental Europe was the low hydro availability while the falling prices after 2008 may at least to some extent be attributed to the economic crisis. Most interesting in this context is that since 2011 the day-ahead prices in virtually all observed countries has decreased almost continuously. The core issue of interest is, what caused this decline?

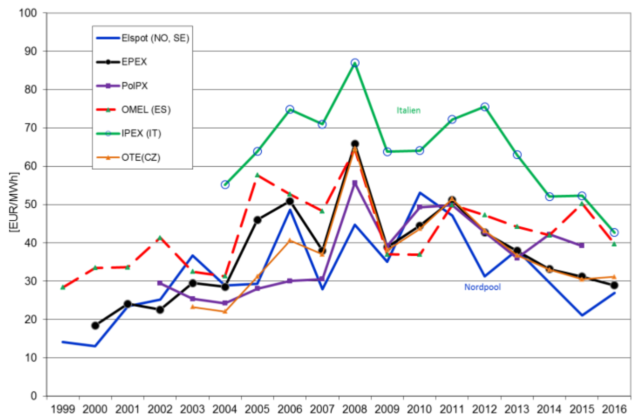

Fig 3. Development of spot market prices in different European electricity markets 1999-2016 (Source: Homepages of different energy exchanges)

3. HOW VARIABLE RENEWABLES IMPACT PRICES IN ELECTRICITY MARKETS

The major reason for this decline in day-ahead prices between 2011 and 2016 can be seen in Fig.1. It is the remarkable rise of variable RES with zero short-term marginal costs. This increase of renewables has started to impact spot prices, trading patterns and the dispatch of conventional generation by about 2011. The explanation is simple. Assume e.g. a sunny day with ample solar generation. Then the supply curve is shifted to the right as schematically shown in Fig 4, which essentially pushes nuclear and fossil fueled generation "out of the market".

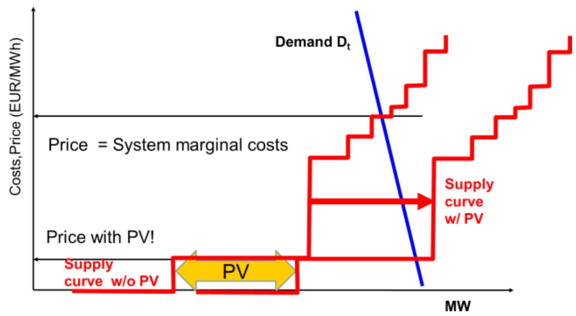

Figure 4. Merit order supply curve with and without additional PV capacities at on-peak time on a bright summer day

This impact of variable RES on electricity prices is already known since volatile hydro power was used for electricity generation. The best example is the Nordic market, mainly Norway and Sweden, where since decades almost only technologies with Zero short-term marginal costs meet the whole supply. In about 2007-2010 – in Denmark already earlier – there was experience with temporarily high wind in the systems and sometimes even negative prices, see also [8]. In recent years increasing production from Photovoltaic system was added to the production portfolios, mainly in Germany, Italy and Spain.

What makes the impact of the aggregate of various variable RES now specifically different? Aside from the above-described effects, variable RES will also influence the costs at which fossil generation – especially natural gas – are offered. The reason is that they would lead to much lower fullloadhours, e.g. only 1000 instead of 6000 h/yr before.

Yet, the revenues earned from these hours must cover both the fixed and variable costs, see also Haas [2]. And in a market with large shares of renewable energy sources the role of conventional capacities will change.

This leads to the following categories of presumed "problems": (i) Prices decrease to Zero or become even negative at a number of days; (ii) Lacking contribution margin to fixed costs for conventional flexible power plants. However, it is not yet clear, on how many days very high and on how many days very low (or negative) prices will prevail and how high or how low these prices will be.

4. A MARKET DESIGN APPROACH FOR SUPPLY SECURITY

One major argument for the call for centralized CM is to retain supply security in the electricity system. The historical (anachronistic) definition of supply security is: At every point-of-time every demand has to be met regardless of the costs. In this context it is important to note that supply security is an energy economic term. It is different from technical system reliability.

The core problem is that so far world-wide the demand-side has been neglected widely with respect to contributing to an equilibrium of demand and supply in electricity markets. Major exceptions are: (i) in the 1980s and 1990s in the U.S., Sweden, Denmark and other advanced countries DSM-measures have attracted attention After the liberalization of the electricity markets most of these programmes disappeared. (ii) In Denmark – the leading country for integrating variable renewables especially wind – has integrated a lot of power-to-heat technologies, that not only play an important role on energy markets, they also cover primary reserve needs. According to [10] power-to-heat technologies can allow for increase of penetration of variable renewables in Denmark up to 40% (with 5-10% curtailment).

The major reason for this ignorance of the demand-side is that in times of regulated monopolies every demand could be met due to significant excess capacities. And still in the liberalized markets huge excess capacities remained. This aspect – to develop the impact of demand-side and customers WTP – is essentialy for a real electricity market and it is actually regardless of the aspect of an integration of larger shares of RES. In the context of the discussion of market design this historical view of supply security plus centralized CM would lead to a new market design in the sense of a centrally planned economy.

On contrary to the central planning approach a market-based one would take into account customers willingness-to-pay (WTP). The equilibrium between demand and supply would come about at lower capacities. It is also important to note that where WTP is lowest the marginal costs (MC) of providing capacity are highest, see Fig. 5. The still applied concept of supply security is anachronistic and contradictory to market principles. It has to be revised in a way that considers customers' WTP;

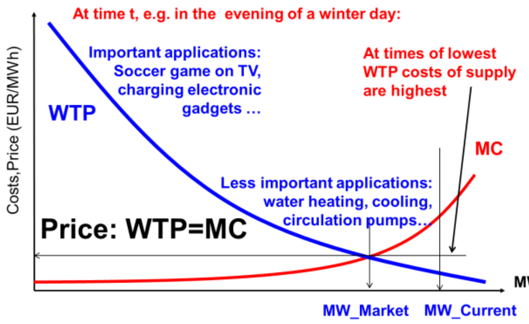

Fig 5. A market-based approach to ensure supply security

5. FLEXIBILITY: THE KEY TERM OF THE FUTURE

Our major findings for integrating large quantities of variable RES-E into the electricity system by using market-based principles and how, straightforward, a sustainable electricity system could work are, that the following conditions have to be fulfilled, see also [2]:

- Most important for integrating larger shares of RES-E in a competitive way is a pricing system that provide information on scarcity or excess capacities at every point-of-time (quarters of an hour);
- Most important to balance variations in residual load is an optimal portfolio of flexibility options which already exists today. Currently these potentials are not fully harvested due to low economic incentives. The most important flexibility options to balance variations in residual load are, see also Fig 6 and [20]:
- short-term and long-term storages such as batteries, hydro storages, or chemical storages like hydrogen or methane;
- Technical demand-side management measures conducted by utilities like cycling, load management;
- Demand response due to price signals mainly from large customers to price changes, time-of-use pricing
- Transmission grid extention leads in principle to flatter load and flatter generation profiles;
- Smart grids allow variations in frequency and switch of voltage levels;

Finally, a demand –side capacity market has to be developed. So far consumers have never been asked what the value of capacity is for them and what they are willing to pay for specific quantities of capacity.

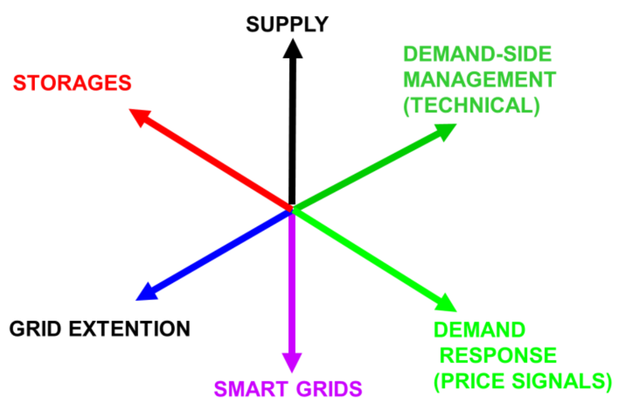

Figure 6. Dimensions of flexibility in electricity markets

4. CONCLUSIONS

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.

The evolution of such a creative system of integration of RES in Western Europe may also serve as a role model for electricity supply systems largely based on RES in other countries world-wide.

Nomenclature

RES electricity produced from renewable energy sources
GHG greenhouse gas emissions

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