ELECTRICITY MARKET DESIGN FOR 100% RENEWABLE ELECTRICITY IN GERMANY

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Kurzfassung:

This paper investigates whether the current German electricity market design is suitable for an electricity system based completely on renewable sources. Following an analysis of the characteristics of a completely renewable system, implications for the market design are deduced and alternative options for the electricity market design are evaluated in a qualitative manner.

Keywords: Strommarktdesign, Erneuerbare

1 Introduction

Electricity is a special good. Unlike most goods and services traded in competitive markets, electricity is essential for the functioning of the economy. Furthermore, demand and supply have to be matched at every point in time as otherwise frequency collapses and electricity supply breaks down. Matching demand and supply however is challenging as electricity is very difficult to store and demand extremely variable. It changes according to time of day, weather or social events. Demand for electricity is also extremely price-inelastic i.e. it does not react to price changes. Ultimately, electricity can be generated using many different technologies with diverse characteristics in terms of costs, emissions and flexibility. The final product however is completely homogeneous and thus there are only limited possibilities for product or price differentiation (Stoft, 2002; Petrov & Grote, 2010; Wawer, 2007a; Heuterkes & Janssen, 2008; Cowart, 2011).Current electricity markets have been designed to maximize benefits in a system based on big centralized conventional power plants. As the electricity sector is changing due to the introduction of an increasing amount of electricity generated from often decentralized renewable sources it is necessary to review the rules and organization of the market. The diverging characteristics of an electricity market based on renewables may need a different market structure in order to maximize utility for society. This paper therefore analysis the characteristics of an electricity system based on completely on renewable sources, deduces implications for the electricity wholesale markets and compares and evaluates alternative market designs in a qualitative manner.

2 Methodology

This paper follows a qualitative research approach. The main reason for this is that there are still large uncertainties regarding the exact characteristics of a completely renewable electricity system, future electricity demand and the degree of European integration to mention just a few factors. By using a qualitative approach it is possible to develop and elaborate general arguments and mechanisms and include a broader spectrum of proposals. Before actually introducing a new market design, more detailed qualitative and quantitative analysis is necessary.

The research was conducted using an in-depth literature review and a number of semi-structures expert interviews. In the paper at hand, only the German market is taken into consideration. Developments on the European level (including the compatibility of proposed market designs with current European law) were excluded from the analysis as on European level future developments are even more unclear and too many uncertainties for deducing valid conclusions would be introduced.

3 Characteristics of an electricity system completely based on renewables – analysis of scenarios

Several organizations have developed scenarios for a German electricity system based completely on renewable energy for 2050. A range of scenarios developed by the German Advisory Council on the Environment (SRU), Greenpeace, WWF, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the German Environmental Authority are analysed in the following in order to identify plausible features of a future electricity system based on renewables (Barzantny et al, 2009; Faulstich et al, 2011; Kirchner & Matthes, 2009; Klaus et al, 2010; Nitsch et al, 2010)[1].

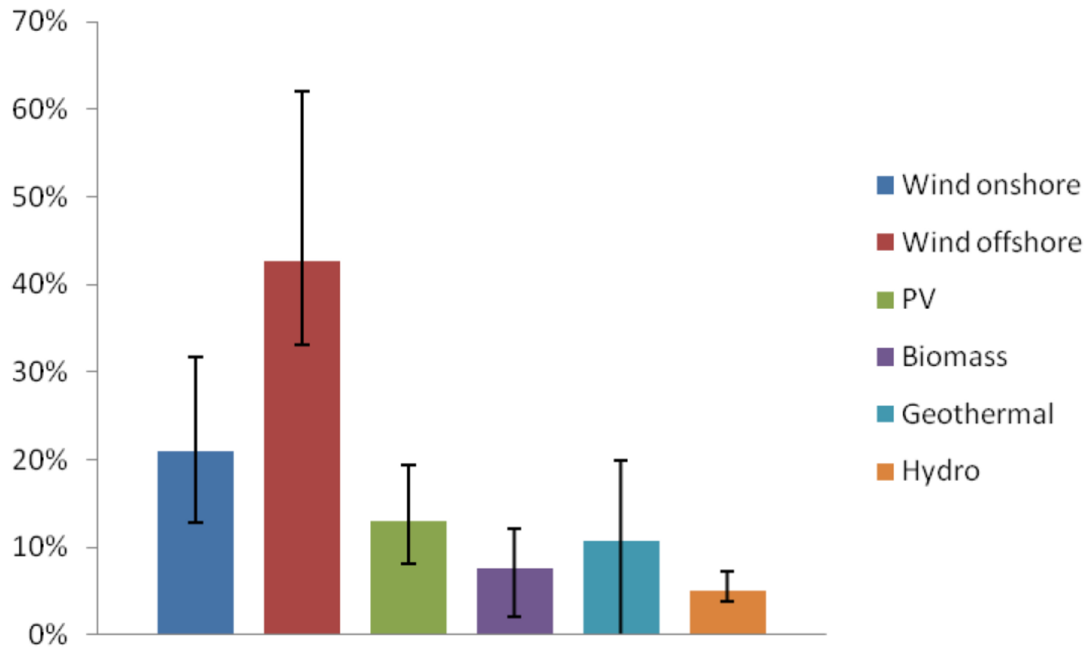

Figure 1: Mean value and range of contribution of renewable technologies to total renewable generation (own calculation)

[1] The SRU provides eight scenarios with different assumptions regarding the import and export of electricity and the level of demand. The analysis at hand includes only two scenarios that allow imports and exports of up to 15% but with a neutral balance of trade in order not to bias the results towards the SRU scenarios. The WWF scenario includes a small share (3.3%) of electricity generation from natural gas as back up for generation from renewables.

Figure 1 shows the mean contribution of different renewable electricity technologies to total renewable generation. The range of percentages is indicated by the error bars. The extent of variation between the different scenarios is striking – the contribution of onshore wind varies between 13 and 32%, offshore wind ranges between 33 and 62%, photovoltaics (PV) contributes between 8 and 20%, biomass between 2 and 12% and geothermal energy between 0 and 20%. Hydro power has values between 4 and 7% and is by far the most stable contributor due to the fact that hydro power is the most advanced of all renewable technologies and many suitable locations in Germany are already developed. An interesting feature of the scenarios is that geothermal energy is expected to become more important than hydro power in all but one scenario despite the fact that initial efforts to use geothermal energy for electricity production in Germany show mixed success. Notwithstanding all differences, wind generation (onshore and offshore) will be the most important technology in a completely renewable electricity system. The mean value for hydro generation is approximately 5%, for biomass around 10% and for PV approximately 15%.

4 Implications for the electricity wholesale market resulting from the differences between the current and a completely renewable electricity system

Following the scenario analysis differences between the current and a completely renewable electricity system can be deduced. These differences lead to a number of challenges for the functioning of the electricity wholesale markets as shown in Table 2 and explained in the following.

Impacts	**Underlying change(s)**
Reduction of average wholesale electricity prices	Changed cost structure
Increased volatility of wholesale electricity prices	Changed cost structure, lower predictability and dispatchability of plants
Changed load profiles for non-variable plants	Changed cost structure, lower predictability and dispatchability of plants
Increased need and costs for balancing and/or intraday adjustments	Lower predictability and dispatchability of plants, less flexibility
Grid congestion and higher need for redispatch	Different location-specific requirements, lower dispatchability
Need to include more diverse actors into the electricity wholesale markets	More diverse ownership structure

Table 2: Impacts of integrating renewable electricity into the electricity wholesale market

4.1 Reduction of average wholesale electricity prices

One important effect of an increasing share of renewables is the ‘merit order effect’ leading to reduced wholesale electricity prices in times of high renewable generation. This has two direct consequences: First, contribution margins for base load, mid-merit and peaking plants decrease in hours of high renewable generation which makes cost recovery for new plants and investment incentives more challenging (Pöyry, 2011). Second, the value of renewable electricity in the wholesale market is lower than that for electricity generated from other sources (Bushnell, 2010). According to Twomey & Neuhoff (2010) this is the case especially for wind which already contributes considerably to overall electricity production and is not correlated with the demand profile.

In a completely renewable electricity system where most plants have low or close to zero marginal costs the continuation of the merit order effect means extremely low prices in the electricity wholesale market for most hours. Only biomass plants and potentially storage plants and demand side involvement can increase these prices.

4.2 Increased volatility of wholesale electricity prices

Pöyry (2009) show for the UK, that price volatility increases substantially with higher shares of variable generation. Both negative prices and high scarcity prices occurred frequently in their simulation. Studies for the German market also predict more volatile and less predictable prices for the EPEX day-ahead market (Nicolosi & Fürsch, 2009). The fact that in 2010 and 2011, peak prices have almost disappeared from the German spot market due to more PV generation and increased competition does not contradict this long-term trend.

For a completely renewable electricity system with a high share of intermittent generation, highly volatile and less predictable prices at the power exchange can be expected due to high wind penetrations. Negative prices will not occur frequently as no extremely inflexible plants (such as lignite or nuclear) will be on the system. For dispatchable plants such as biomass, hydro, to a certain degree geothermal and storage plants, high scarcity prices counteract the merit order effect and can enable cost recovery even at low utilization rates. Variable plants can profit from high scarcity prices as well. However, they will mostly not be generating at these times and thus face on average lower electricity prices. For storage plants, highly volatile prices can be a benefit as they can profit from the spread between very low purchase prices and extreme selling prices for electricity. However, this is complicated by the difficulty of predicting price levels. In general, the lower predictability of prices leads to problems for planning investments due to lower planning security (Pöyry, 2011).

4.3 Changed load profiles for non-variable plants

The variability of a high share of generation in a completely renewable system also leads to changed load profiles for non-variable plants (Pöyry, 2011; Nicolosi, 2010; Obersteiner & von Bremen, 2009; MacCormack et al, 2010). Already, mid merit and base load plants have to reduce their operating hours. Bode and Groscurth (2011) show this for the effect of PV generation on coal plants.

In a completely renewable system, dispatchable plants must react flexibly to changes in production of intermittent sources to satisfy residual demand. Base load and mid merit plants will not exist in this system. The premium and flexibility premiums under the new EEG aim at incentivizing a more flexible operation of biomass plants.

4.4 Additional challenges

While the above listed challenges all lead to a reduction of incentives to invest into new power plants and challenges regarding cost recovery for existing plants there are also a number of challenges concerning the short term functioning of the electricity wholesale market.

First, the lower predictability of renewables leads to an increased need for balancing and/or intraday adjustments. Especially the deviation of actual wind generation from day-ahead forecasts becomes increasingly important at higher penetration rates (Weber, 2010; Obersteiner & von Bremen, 2009). Thus, either more balancing reserves are required or intraday trading needs to be extended. Another problem for balancing intermittent generation in a completely renewable system is that fewer power plants are available to provide the full spectrum of current balancing services. The reduced number of possible participants in the market especially for positive balancing services can reduce liquidity and increase prices in these markets (Erdmann, 2008; von Roon, 2011).

Second, wind parks are so far mostly built in Northern Germany while the highest demand for electricity occurs in the South of the country (Moser, 2009; DENA, 2010). Therefore (and because thermal plants are planned and built close to the coasts as well to reduce fuel transport costs), increasingly large amounts of electricity need to be transported from North to South. Regular grid congestion along the North-South corridors is therefore expected (Neuhoff, 2011).

Third, in a completely renewable electricity system, more diverse plant operators including farmers, communities and households will be part of the system. This is probably even true if current efforts of incumbents to invest in big renewable generation units are taken into account. The current market rules however make the participation of diverse actors difficult.

5 Options for making the electricity market fit for the future

As the challenges for cost recovery and investment incentives were identified as the most important issue by most expert interviewees, this section focuses mainly on this problem. However, it must be noticed that there is still an ongoing discussion whether energy-only markets are suited to allow for high enough scarcity prices in periods of low excess capacity to provide sufficient investment incentives even in a conventional system (Joskow, 2006).

There are four ways to reconcile the electricity market design with the new electricity system. The first is to make the new electricity system more like the old one in order to have plants bidding into the market at considerable marginal costs and avoid extra-balancing. The second is to adapt the current electricity market design. The third is to add new components to the current market design to compensate shortcomings. The last and most radical one is to change the electricity market design fundamentally and introduce completely new rules for trading electricity.

5.1 Making the completely renewable system more like a conventional one

The renewable electricity system can be made more similar to the current one by aggregating different renewable generation units into bigger entities delivering dispatchable electricity e.g. through a combination of wind parks and biomass plants. Such 'virtual power plants' are similar to conventional power plants but are not operated at one location.

However, there are several drawbacks of such a development: First, balancing needs in an electricity system can be minimized by including a large area into one balancing zone (Fussi et al, 2011). While system operators do not need to contract extended balancing services for increasing variable generation, the 'virtual power plants' contract much higher volumes of back-up and balancing plants. As a consequence, costs of electricity for consumers increase (Consentec & r2b, 2010). Second, grid congestion issues cannot be easily solved in such a system as one market participant feeds in electricity at different locations. As a consequence, the introduction of 'virtual power plants' is no sufficient solution for the problems identified.

5.2 Making the current market design fit for a completely renewable system

Another option to avoid major restructuring of the electricity market design is to take care of the changes from a conventional to a completely renewable electricity system by adapting the current market design to the new challenges. The current market includes the spot (day-ahead and intraday trading), the forward and the balancing market. Rules in all these markets can be changed. There are several proposals to address investment incentives and cost recovery within the current market design.

5.2.1 Changed pricing in the electricity spot market

One proposal is to change the pricing mechanism in the electricity wholesale market to pay-as-bid pricing as currently used in the balancing market. In theory, under pay-as-bid pricing, generators bid at a price that ensures recovery of their total costs (Nielsen et al, 2011). However, this is not necessarily the case as plants need to be dispatched in order to recover costs at all. Especially plants with high capital costs and low operational and marginal costs are incentivized to ensure dispatch as often as possible (Varian, 1996; Tierney et al, 2008). Empirical analysis so far does not prove that pay-as-bid auctions are preferable to unit price auctions regarding cost recovery and investment incentives. Furthermore, they do not produce a unique reference price and have disadvantages for smaller market participants (Ockenfels et al, 2008).

Another way is to allow for complex bids so that the market operator is informed about both marginal and average production costs of market participants. Dispatch follows marginal costs in order to minimize system costs and fuel needs while remuneration is based on average production or long term marginal costs. A similar method was used in the former monopolistic system (Kogelschatz, 2004). Such a regulation implies however several problems: The information asymmetry between generators and market operator can be used for influencing prices, the German power exchange operator is currently not prepared to act as a dispatch and market facilitator and bilateral trading outside the power exchange would not necessarily follow the new rules.

Therefore, it is rather complex to ensure pricing based on average production costs in the electricity market. Furthermore, a change of the pricing mechanism can lead to inefficient dispatch and crowding out of technologies with low marginal costs.

5.2.2 Changed pricing and longer-term contracts in the forward markets

It is often argued that investors in assets with high capital and comparatively low operational costs need long term contracts or other hedging opportunities in order to realize investments. Currently, no contracts with sufficiently long durations to hedge investment risks are traded at the EEX. While there are possibilities for entering into long term agreements in OTC trading, transaction costs linked to such undertakings are considerable – which is always a disadvantage for smaller generators. As a consequence, the introduction of longer term contracts at the EEX and encouraging payments according to long-term average costs is an opportunity to enhance cost recovery and investment incentives for electricity generators.

Prices in the forward and futures markets do not differ systematically from spot market prices due to arbitrage opportunities. There is however some evidence for risk premiums in the market. These may become higher in the future anyway as the risks in the spot market augment due to the possible increase in price volatility. Furthermore, the more volatile and more difficult to predict spot market prices are less of a reference and thus their lower average level must not necessarily influence the price level of long term contracts. Spitzen (2010) finds that the variance and skewness of spot prices have already lost their significance for explaining the risk premiums in forward markets.

However, there are some difficulties with new long-term contracts. First, arbitrage possibilities between the forward contracts and the electricity spot market will still exist. Second, in case of the EEX it is questionable whether the introduction of additional long term products will attract enough liquidity to make these products a selling option for generators. In addition, pricing of future contracts cannot be influenced under the current market design as the price is determined in bilateral negotiations both in OTC trading and at the EEX.

5.2.3 Improved income opportunities in the balancing market

The balancing market offers an additional opportunity for generators to recover investment costs. As described above, balancing needs will increase in a completely renewable electricity system at least if the intraday market does not become sufficiently liquid and flexible. Current pricing mechanisms in the balancing market are rather complex. Therefore it is hard to predict how balancing prices will evolve in a system based completely on renewables. On the one hand, lower average prices in the electricity wholesale market lead to low opportunity costs when participating in the balancing market and thus reduce balancing prices. On the other hand, as many plants cannot participate in the balancing market to full extent, this leads to upward pressure on prices.

A very important aspect for balancing is the currently limited participation of renewable sources in this market. While the involvement of dispatchable sources such as biomass or hydro plants does not cause problems, the participation is more challenging for intermittent sources. However, wind energy and other variable sources can provide negative balancing which achieved higher incomes at least in 2010 (Consentec & r2b, 2010). The necessary reorganization of the market including lower minimum capacities, less restrictive technical requirements and shorter contract time frames has already started (Speckmann, 2011).

Additional income from the balancing market can contribute to cost recovery for both variable and dispatchable power plants in the future. However, the balancing market volume is not high enough to ensure investment incentives and the future development of prices in the balancing market is not clear from the current point of view.

5.2.4 Measures to tackle additional challenges

In order to react to increased balancing requirements or intraday adjustments the balancing market can be made more flexible to enable more diverse actors including all kinds of generators irrespective of size and technology and the demand side to participate in the market. First steps have already been taken as minimum sizes and bidding periods for the different types of reserves were reduced. These efforts need to be continued (Speckmann, 2011; Obersteiner & von Bremen, 2009; Thomas, 2011). In addition, wind forecasts need to improve and intraday trading facilitated in order to make use of the new information regarding generation from variable sources available closer to real time (Borggrefe & Neuhoff, 2011).

The most suggested solution for tackling grid congestion is ‘nodal pricing’. This is currently widely used in the US and implies that separate marginal prices are derived at each node in the grid. As a consequence prices differ between locations according to grid congestion and generators are incentivized to adapt their production in order to minimize congestion (Neuhoff, 2011).

In order to facilitate the integration of more diverse actors on the supply and demand side into the electricity market, rules must become more flexible and easier to understand to reduce transaction costs, time frames for bidding must be reduced and products become more flexible. A centralized agency for selling energy from smaller producers into the market can also be beneficial.

5.2.5 Summary and assessment

It is difficult to change the current electricity wholesale market in order to ensure cost recovery and investment incentives – notwithstanding the possibility that the current market is sufficient to provide these anyway. It is however possible to resolve the challenges of involving more diverse actors into the market and minimizing and fulfilling the need for increased intraday adjustments and balancing within the current market design. The question of grid congestion depends on the level of marginal prices – reliable solutions will probably include measures such as grid extension.

5.3 Add-ons to the current market design

If the current market design does not deliver cost recovery and sufficient investment incentives the next possibility is to add further market components.

5.3.1 Capacity mechanisms

Capacity mechanisms consist of an availability payment for generators which is added to the income from the electricity market. There are two main types of capacity mechanisms – price-based and quantity-based. In price-based mechanisms, the tariff paid by the system operator to the generator is defined by the administration. In quantity-based mechanisms, the system operator sets the quantity needed and the corresponding price is defined by market forces. Capacity markets can be added in quantity-based systems (Pfeifenberger et al, 2009).

Forward capacity markets were identified as most successful in generating investment incentives in several analyses of different capacity mechanisms (Pfeifenberger et al, 2009, Süßenbacher et al, 2011; Lopez-Pena et al, 2009; Castro-Rodriguez & Siotis, 2010). Therefore, only this type of capacity mechanism is explained in more detail in the following. In capacity markets, the system operator defines a level of capacity that will be needed at a certain point in the future to meet peak demand. Electricity suppliers are obliged to buy this capacity ahead of time either bilaterally or at the capacity exchange. Capacities include generation, demand and storage assets (Süßenbacher et al, 2011).

When using capacity markets for a completely renewable system, several specific aspects need to be considered. The involvement of demand response and storage assets needs to play an important role. Payments to plants that are not suited to complement the system and ensure reliability and security of supply such as inflexible biomass plants must be avoided (Cramton & Stoft, 2005). Another issue is that capacity markets are targeted at firm capacities that can be relied upon when called at any time. Therefore, the involvement of variable sources and the original idea of capacity mechanisms to ensure security of supply are not compatible. A number of issues have to be considered when designing a capacity market as no common design exists so far and capacity mechanisms already in place internationally all have significant disadvantages. A completely renewable system requires additional adaptations. Therefore, any design must be tested rigorously before actual implementation.

5.3.2 Support for intermittent sources

As capacity markets are probably not a good means to support intermittent sources, a different mechanism is necessary. Feed-in premiums (FIP) are currently used in Spain and in Germany since January 2012. In a completely renewable system, FIP can be used to support intermittent sources, hedge their risks regarding cost recovery and keep investment uncertainty acceptable by using a 'cap and floor' or sliding system. This keeps these sources reacting to market mechanisms and prices but also stabilizes their income stream. Petrella & Sapio (2009) find for the Italian market that sliding premiums can reduce price volatility in the electricity wholesale market.

As with fixed FIT, the challenge for the government or system operator lies in setting the right FIP or FIT-CfD level incentivizing sufficient investment but avoiding windfall profits to generators. Furthermore, FIP imply higher investment risks than FIT and are thus less attractive especially for smaller market players (Nestle, 2011).

5.3.3 Summary and assessment

Capacity markets for dispatchable generators and FIP for intermittent sources provide cost recovery and investment incentives if carefully designed. The effects of capacity markets on market power need to be taken into consideration when designing this market in order to avoid gaming opportunities. Electricity wholesale and balancing markets provide efficient dispatch and balancing in this setting. The other issues (grid congestion, more diverse actors and increased need for balancing and intraday adjustments) can still be treated as described above. In addition, locational signals can be included in the capacity market design. FIP can also provide signals for efficient locational choices. FIP and capacity markets increase investment security and hence facilitate the involvement or more diverse actors. A prerequisite for this is however that at least a considerable part of the income for generators comes from the normal electricity wholesale and balancing markets. Otherwise, there is no incentive for generators to participate in these markets at all. Especially the challenge of making the intraday market more liquid is dependent on income that can be generated from this market in order to motivate market players to actively participate.

If electricity wholesale and balancing markets will not produce considerable income for generators in the future, generators will mostly rely on the add-on mechanisms i.e. capacity markets and FIP to get their income. In this case, the electricity wholesale market moves away from a competitive market as we know it at the moment. This effect is explained in more detail by Bode & Groscurth (2011). They describe a system with fixed FIT for all renewables and capacity payments for conventional sources. Their argumentation is nevertheless valid. For both capacity markets and FIP, the system operator or the government define and forecast parameters such as the amount and characteristics of capacities needed in the future and the level of support for intermittent sources. However, both suggested add-ons are market-based instruments and payments can be adapted over time to real costs.

5.4 More radical changes

In order to identify a suitable market design it is worth to explore more radical alternatives and new market architectures – some of the more promising ideas for such a restructuring are presented in this section. This list of proposals is not comprehensive but includes a range of approaches.

5.4.1 A pool market following the North American example

The pool market design is advantageous in relation to a high share of intermittent sources in several ways. A more liquid intraday market and later gate closure as well as the non-separation between balancing and intraday markets ensure the ability of the market to incorporate improved generation forecasting of intermittent sources closer to real time (Borggrefe & Neuhoff, 2011). Many pool markets implement nodal pricing. Hence, the existing grid is used more effectively and grid congestion is minimized. Furthermore, the participation of more diverse actors in the market is facilitated as the more liquid market facilitates market entry.

In terms of cost recovery and investment incentives however, the existing pool markets also rely on capacity markets and other add-on mechanisms while pricing in the pool is based on marginal costs. According to Newbery (2004), the pool model is more prone to market power than a bilateral market as the private actors have an information advantage. Thus, all issues but cost recovery and investment incentives and possibly market power can be sorted with a pool market. However, as described above, the same applies for the current bilateral system.

5.4.2 Long term feed-in tariffs

One option to provide long term investment security is to continue to pay fixed feed-in tariffs (FIT) to all renewables and thus in the future to all generators. This guarantees cost recovery and investment incentives. FIT are also a good means to avoid market power and involve diverse actors into electricity generation. Windfall profits can be avoided by constantly reducing rates following the learning curves of different technologies (Gross & Heptonstall, 2010). With FIT for all generators electricity generation is however decoupled from demand as generators under FIT profit from every extra kilowatt hour they produce regardless of whether it is needed or not. This leads to increased balancing needs. The same is true for grid congestion problems. Thus, in such a system, grid infrastructure as well as storage capacities must be high enough to provide all necessary transportation and balancing to serve electricity demand at all times. This implies considerable costs (Neuhoff, 2011).

5.4.3 Technology-specific auctions and long term contracts

Another option for restructuring the electricity market and introducing adequate investment signals to replace the existing fleet and enable cost recovery for investors is technology-specific auctions for long term contracts. An example for such a system is Brazil. The main difference between the technology-specific auctions described in this chapter and the capacity markets is that generators under technology-specific auctions do not only receive a price for availability but at least for intermittent sources long-term payments for electricity generation similar to a FIT system are included. Therefore, the electricity wholesale market loses much of its importance and efficient dispatch must be organized in a different more centralized way.

In the Brazilian system, this mechanism is used as the electricity mix is dominated by hydro plants with high fixed costs and very low marginal costs. Their generation is dependent on the weather and highly reduced in dry years. Thermal plants are called upon very rarely. Thus, for both generation types, investment conditions are difficult (de Castro et al, 2010). Auction winners usually receive long term contracts often including a price for availability and electricity production (ibid.). This kind of market model implies a competition for the market as the income from long term contracts is defined in a competitive auction process such as the one proposed for capacity markets.

Bode & Groscurth (2011) propose technology-specific auctions for all renewables but differentiate between intermittent and dispatchable sources. For intermittent sources, generators bid at a price per kilowatt hour of electricity production. The auction outcome is a contract for a certain amount of electricity to be produced over the next twenty years. If the electricity is produced earlier or later, the contract ends earlier or later respectively. For non-intermittent sources, the contract is based on availability payments like in a capacity market in order to ensure that sufficient generation, storage and demand response is available at times of low generation from variable sources. All auctions are supposed to include specific locational and technological requirements in order to support the development of an efficient electricity system and minimize grid extensions. In a completely renewable system, the proposal implies the end of the current market design and a return to central planning and dispatch as in the state monopoly but with existing private companies and competition for the market.

However, there are several potential drawbacks of such an approach. First, technology-specific auctions imply that a central instance defines the capacity need for each technology. Thus, there is a danger of technological lock-in and disregarding alternative technologies. Second, the experience with auctions as support mechanisms for renewables in the European context has so far been rather unsuccessful. However, in a system already based completely on renewables, auctions can be an appropriate tool for determining long term contract conditions if the technologies are well known and the market is competitive (Skea et al., 2011).

In terms of the additional challenges, technology-specific auctions can have positive impacts if adequately designed: Grid congestion can be avoided by placing new generation capacity at locations with sufficient grid infrastructure. The optimization of grid extensions and capacity planning can be a combined process. Dispatch can be efficient and extensive balancing avoided if the central mechanism is based on sufficient information and includes flexible intraday adjustments. Auctions also need to be designed in a way that facilitates the participation of diverse actors including storage operators, demand side and decentralized generation. Care must be taken in order to not exclude smaller or new actors from participating in the auctions.

5.4.4 State monopoly

As the electricity system is becoming more complex and more separate regulations for investment in renewables and flexible capacities are introduced, some authors demand the return to a state-owned monopolistic system. Another reason for this claim is that prices for final electricity consumers have not been reduced in the long term by privatization when affordability was one of the main reasons for breaking up the monopoly in the first place (Möst & Genoese, 2009; Sioshansi, 2006). A state-owned monopoly can be advantageous as there are no information asymmetries between generators and the system operator and thus no gaming. Furthermore, grid infrastructure can be optimized at the same time as storage and generation reducing overall system costs.

However, there are severe drawbacks from the reintroduction of a state-owned monopoly. Historically these monopolies have mainly focused their efforts on security of supply. The result was huge overcapacities. There is no reason to assume that this will be different after a renewed nationalization of the electricity system. In addition, competitive markets tend to spur innovation which is important for the development of new technologies (Markard & Truffer, 2006; Kwoka, 2008). Another problem is that a completely renewable system is much more complex than the conventional one as generation units are smaller and more decentralized and demand side involvement and storage are additional necessary components. A centrally organized state monopoly is problematic when it comes to build, operate and optimise such a system.

Thus, a state monopoly offers several advantages due to its simplicity and good investment environment. However, lower innovation and higher prices as well as the increased diversity and complexity of the electricity system have to be considered. Furthermore, all problems related to public forecasting of future trends and central planning discussed above are relevant.

5.5 Assessment of different market designs

Table 3 shows an overview of the market design options described above and their performance regarding challenges identified as well as four additional criteria– degree of change, affordability, simplicity and public acceptance. These are applied for the following reasons:

Degree of change

Market participants perceive a higher political risk with frequent regulatory changes (Gross et al, 2007; Blyth et al, 2007). Furthermore, reforms always incur costs. As a consequence, options that imply a lower degree of change are preferable if their performance is similar.

Simplicity

Simple market designs are generally preferable. They are easier to understand for market participants and thus facilitate the involvement of more diverse actors. In addition, they cause lower transaction costs, are more transparent and less prone to market power (Baker et al, 2010).

Cost efficiency

Affordability is one of the main energy policy objectives apart from emission reduction and security of supply (BMWI & BMU, 2010). Therefore, the cost efficiency of a system is crucial amongst other factors for political acceptance.

Public acceptance

Public acceptance is currently one of the major problems for investment in grid infrastructure and generation assets. While it is not necessary for the general public to understand the details of an electricity wholesale market design, the implications of some market designs are more acceptable than those of others. Accepted market designs can be more effective in achieving their objectives due to lower public resistance.

Table 3 shows that there are several options to tackle the most important challenge of cost recovery and investment incentives, namely the add-ons to the current market (FIP and possibly capacity markets), long-term FIT for all generators, technology-specific auctions and the state monopoly. These options differ in their performance regarding the remainder of the criteria.

The add-ons to the current market design can solve all challenges posed by a completely renewable system. However, they require a medium level change in the system as new components are introduced. Furthermore, it is not clear whether the public will accept the additional support mechanisms and whether cost-efficiency can be reached, as FIP level and capacity needed are defined by a central agency. The biggest challenge for these add-ons is that the market will become increasingly complicated.

The options for long term contracts – long term FIT and technology-specific auctions – imply challenges regarding several of the other problems. FIT provide for the involvement of different actors and reduce market power, but are problematic with respect to congestion and balancing. Public support is a problem for FIT as already now, complaints about high payments prevail. It is however dependent on their cost efficiency in the long term which is hard to predict at this point in time. Nevertheless, FIT are especially attractive due to their simplicity and because this system is already a part of current regulation. Technology-specific auctions imply problems regarding the involvement of diverse actors and market power – which can be sorted by adequately designing the auction process. Balancing and intra-day adjustment issues can be solved by including availability payments in the contracts. As a relatively simple tool, such auctions are a viable alternative to the current market design even if they imply a high degree of change and their performance in terms of cost efficiency and public acceptance is not clear yet.

A state monopoly provides a seemingly simple solution. However as described above the complexity and decentralised organisation of a completely renewable system make central planning very difficult. The fact that there are no diverse actors in the monopoly in combination with probably high costs involved, the uncertainties regarding public acceptance and the high degree of change needed make this proposal rather unattractive. In addition, there are problems regarding innovation and raising of private money for investments.

Due to remaining uncertainties, it is difficult to decide about the optimal market design for a completely renewable electricity system in Germany at this point in time. Nevertheless, the assessment in this section has identified some promising market options.

Amongst the options not leading to cost recovery and investment incentives, the current market design with adaptations is worth a closer look. As discussed above, the current market design performs well regarding the other challenges from a completely renewable system, with grid congestion depending on the level of infrastructure and prices in case of the introduction of nodal pricing. It is a simple system as more flexible and easier rules are required for the involvement of more diverse actors and no additional payment schemes for available capacity exist. Keeping the current market architecture requires no change and thus implies little regulatory risk. If competitiveness prevails, this system can also lead to cost efficiency. Also, it cannot be ruled out at this point in time that the current market design can provide for cost recovery and investment incentives even if this is highly unlikely especially for variable sources.

If cost recovery and investment incentives cannot be achieved, the next option is the current market design with add-ons. However, this market design has one main drawback – complexity. Therefore before actually introducing the add-ons, some of the more radical options must be further examined. It is possible that long-term FIT or technology-specific auctions can be designed in a way to tackle all challenges posed by a completely renewable system and provide a simpler solution. Thus, a careful cost-benefit analysis of these three options is necessary.

Type of market	Cost recovery/ investment incentives	Balancing/ intraday adjustments	Grid congestion	More diverse actors	Market power	Degree of change	Cost efficiency	Sim-plicity	Public acceptance
Current market with virtual power plants	?	√√	??	?	?	None	???	?	?
Current market design	??	?	?	?	?	None	?	?	?
Current market design with adaptations	??	√√	?	√√	√	Low	?	√	√
Current market design with add-ons (FIP and possibly capacity markets)	√√	√	√	√	√	Medium	?	??	?
Pool model	??	√	√	√	?	High	?	?	?
Long-term FIT	√√	?	?	√√	√√	Low	?	√	√
Technology-specific auctions	√√	?	√	?	?	High	?	√	?
State monopoly	√√	√√	√√	n/a	n/a	Very high	?	√√	?

Table 5: Different market designs and their advantages and disadvantages for a completely renewable electricity system

Legend: **√√ Objective reached,**
√ Objective most probably reached
? Objective maybe reached
?? Objective unlikely to be reached
??? Objective highly unlikely to be reached

6 Conclusion and policy recommendations

Before defining the optimal market design for a completely renewable electricity system, further research is necessary regarding several aspects. First, the characteristics of a completely renewable system including storage and demand side involvement need to be further elaborated. Second, the performance of the current market design regarding investment incentives and cost recovery must be evaluated. Third, options identified as promising need to be assessed in more detail. Fourth and last, when an adequate market design is identified, steps to reach this market design need to be developed. Based on all research, an optimal way to integrate renewables into the market design can be deduced.

Market changes always increase political risks and therefore increase investment costs for new plants. It is therefore recommended, to test a new market design in detail and to clarify costs and benefits before introducing the change. As it is not clear yet whether the current market design is the right one for the future, it also does not necessarily make sense to bring renewables closer to the market at this point in time. Nevertheless, the optional introduction of FIP is reasonable in order to better understand the impacts of renewables actively participating in the market. Moreover, it is recommended to facilitate the integration and participation of renewables in the balancing market. In addition, a distinction between variable and dispatchable sources makes sense already now. Dispatchable renewables such as biomass need to be incentivized to become more flexible. Here, a stronger instrument than optional FIP is necessary. Policy also needs to consider the trade-off between waiting for all necessary research to be completed and the need for action to incentivize adequate investment and ensure security of supply with an increasing share of variable generation. It is crucial to set the right investment incentives, maybe using non-market instruments, while the restructuring of the market design can also occur at a later point in time.

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