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An optimal mix of conventional power systems in the presence of renewable energy: A new design for the German electricity market

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ABSTRACT

In this paper we develop a new market design for the German electricity market. Our new market design simultaneously ensures security of energy supply and ongoing expansion of renewable energy (RE). The methodological approach applied considers the special challenges resulting from the intermittent nature of RE – we simulate developments in the German electricity market between 2015 and 2034 and differentiate across various power plant technologies according to their ability to flexibly react to changes in the residual load. In theory, a composition of power plants that is optimally adapted to residual load always leads to the most cost efficient supply of electricity. However, our empirical analysis demonstrates that this does not necessarily lead to an improved market environment, both in terms of power plant profitability as well as uninterrupted power supply.

1. Introduction

Compared to the rest of the world, German consumers largely enjoy a secure electricity supply (defined as a permanent and sustainable coverage of demand for electricity). The average ‘unavailability’ of electricity per customer in 2012 was 15.91 min (Federal Network Agency, 2013). Uninterrupted delivery needs to be ensured both during peak load hours, as well as in the event of technical problems that lead to unexpected downtimes of (conventional and renewable) power plants (BMWi, 2012). In this context, an undergoing transformation of German energy policy poses major challenges to uninterrupted electricity supply in the near future. On the one hand, the gradual phasing-out of nuclear power, as decided by the German government in early 2011 after the events in Fukushima, is expected to lead to a considerable reduction of conventional generating capacity (Bundesgesetzblatt, 2011). Moreover, as a result of increased air quality standards, some older coal-fired plants will also shut down (European Union, 2010; BDEW, 2012). On the other hand, the increasing infeed of renewable energy (RE) also represents a further threat to the security of electricity supply. In order to counteract the expected strong fluctuations caused by RE reliance, it will be necessary to have a significant amount of controllable power plant capacity. Due to its close to zero marginal costs and the priority purchase obligation for its use, the increasing amount of RE does, however, lead to a reduction in the market price of electricity and the displacement of conventional power plants (Lang, 2007; Wüstenhagen and Bilharz, 2006; Federal Ministry of Justice, 2014). Hence, the profitability of conventional power plants may deteriorate to such an extent that many power plant operators are forced to consider closing down their plants (Sensfuß et al., 2008; Sorge, 2013).

Against this background, the ability to maintain a high level of supply security is already endangered in some regions in Germany (Amprion et al., 2013), with substantial energy deficits expected in the medium to long term (Matthes, 2012). As a temporary countermeasure, the German Federal Government has introduced a provision for procuring power reserves. Under this provision (and in return for an appropriate remuneration), those power plants considered to be indispensable for maintaining the security of supply are kept as a reserve

Abbreviations: BL, Base Load; BLPP, Base Load Power Plant; CCGT, Combined Cycle Gas Turbines;; CM, Contribution Margin; CPP, Full Power Plant Capacity; EEG, Erneuerbare Energien Gesetz (Renewable Energy Sources Act); FCPP, Annualised Fixed Costs of Power Plant; GT, Gas Turbines; GWh, Giga-Watt hours; I, Intersection; LDC, Load Duration Curve; LDCM, Load Duration Curve Model; MCB, Marginal Costs of Base load power plant; MCM, Marginal Costs of Medium load power plant; MCP, Marginal Costs of Peak load power plant; MCPP, Marginal Cost Curve of Power Plant; ML, Medium Load; MLPP, Medium Load Power Plant; MO, Merit Order; MW, Mega-Watt; MWh, Mega-Watt hours; NPV, Net Present Value; P, Price of electricity; Peak, Peak load pricing; PDC, Price Duration Curve; PL, Peak Load; PP, Power Plant; PLPP, Peak Load Power Plant; RE, Renewable Energy; RLDC, Residual Load Duration Curve; TCM, Total Contribution Margin of power plant; VoLL, Value of Lost Load

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outside the actual energy markets (Federal Ministry of Justice, 2013a, 2013b). Provisions for interruptible loads represent a further measure for ensuring a stable supply of electricity. Such provisions for interruptible loads would oblige energy-intensive companies to reduce their amounts of demand for a certain period in exchange for an agreed remuneration (Federal Ministry of Justice, 2013c). Such regulations are seen as temporary solutions with the intention to introduce a fundamentally new design for the electricity market in the near future. The goal of the new market model is to ensure a permanently secure supply without having to compromise on further expansion of RE.

To our knowledge, our analysis provides the first attempt to develop a new market design that simultaneously ensures security of energy supply as well as ongoing expansion of RE. In contrast to the existing literature (e.g. Nicolosi, 2012; Peek, 2012a, 2012b; Batlle and Rodilla, 2010; Boot and van Bree, 2010; Briggs and Kleit, 2013; Cramton et al., 2013; Gottstein and Schwartz, 2010; Keay-Bright, 2013; Meyer et al., 2014; Matthes et al., 2012; Neuhoff et al., 2013; Perkins, 2014), the methodological approach applied here explicitly considers the special challenges resulting from the intermittent nature of RE– we simulate developments in the German electricity market between 2015 and 2034 and differentiate across various power plant technologies according to their ability to flexibly react to changes in the residual load. Accordingly, the paper provides new insights both to the scientific community and policy makers; this can serve as guidance for selecting adequate instruments that simultaneously ensure a stable security of supply and the extension of renewables in a sustainable manner.

In the next section we present current alternative views on the need for a new market design, as well as review relevant energy models in the literature. Section 3 presents the theoretical approach to the development and subsequent analysis of a new market model, based on the considerations put forward in Section 2. Section 4 analyses the need and practicality of new market designs using empirical data. Finally, Section 5 summarises our main findings.

2. Electricity market designs: mechanisms and adequacy

2.1. The German energy-only market: concepts and background information

As the current electricity market in Germany is operating on the basis of actual (rather than potential i.e. available capacity) production, it is commonly referred to as an energy-only market. In relation to the total amount of electricity consumed, a relatively small proportion is traded on the spot market; the greater part is procured by direct supply contracts (Garz et al., 2009). However, regardless of the form of the contract, all prices are geared to those on the spot market, as deviations would provide scope for arbitrage.

In line with microeconomic theory, an operator offers the output of a power plant at its marginal cost (Varian, 2004). On the energy exchange market, all bids are collected and ranked in an ascending order according to individual marginal costs (offering prices; see Bode and Groscurth, 2006). This produces a prioritisation scheme for power plants with different marginal costs, which is termed the merit order (MO), and corresponds to the supply curve of the electricity market. The energy exchange accepts bids, beginning with the lowest ones, until the demand-side quantity of electricity is met (Henriot and Glachant, 2013). The price of electricity is determined by the last bid accepted that satisfies demand (Wirth, 2013). According to peak load pricing theory, the peak demand price must be above the marginal cost of the most expensive type of power plant in order to ensure that these plants can cover their capital costs (Pillai, 2010). Basically, the marginal costs of a conventional power plant depend upon its net efficiency, the respective fuel and CO_2 emission costs, and other variable operating and maintenance costs (Lang, 2007). Fig. 1 displays the MO (supply curve) for conventional power plants and the corresponding demand for electricity on the energy exchange spot market.

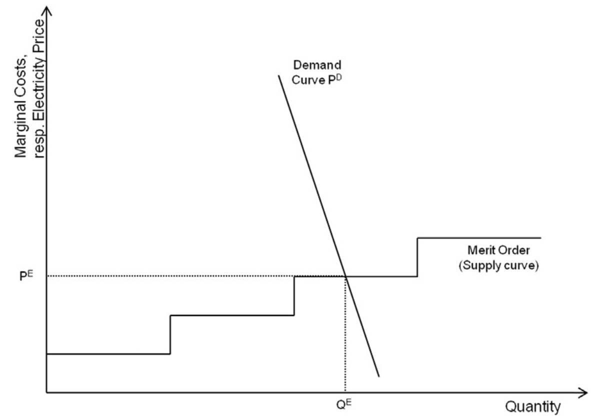

Fig. 1. Schematic supply and demand curve on the spot market.

RE in Germany is largely incentivised through the country's Renewable Energy Sources Act ("Erneuerbare-Energien-Gesetz" - EEG). Under this act, operators of renewable energy power plants are paid for the generation of their supplied electricity (by the transmission network administrators) according to fixed tariffs set by the state (Lesser and Su, 2008; Couture and Gagnon, 2010; Schleicher-Tappeser, 2012). Electricity from RE is generally subject to a prioritised arrangement in Germany. Under this arrangement, the operators of public transmission networks must positively discriminate in favour of electricity generated by renewables, before purchasing electricity generated from other energy sources (Federal Ministry of Justice, 2014). Since the introduction of the amended EEG in 2014, new RE power plants are expected to carry out a mandatory level of direct selling depending on their installed capacity. On the exchange market, this green energy is traded on an equal footing with conventionally produced electricity and sold at the same price.

In general, RE has minimal marginal costs in the form of variable operating and maintenance costs. Typically, when the electricity generated from RE is traded on the energy exchange market, this leads to significant changes in the MO (Paraschiv et al., 2014). The diagram below shows that, owing to its marginal costs close to zero, the additional supply of RE is at the leftmost end of the MO-curve, thereby resulting in the original supply function shifting to the right and the equilibrium electricity price falling - this is commonly referred to in the literature as the merit order effect (MOE) (Sensfuß et al., 2008; Felder, 2011; Henriot and Glachant, 2013). The MOE of RE is dependent upon the gradients of the supply and demand curves on the one hand, and the quantity of RE provided on the other.

This downward effect of RE on spot market prices can be observed even when the generated quantity of RE is not traded on the energy exchange market. Owing to the aforementioned obligation of transmission network operators to give priority to RE during electricity procurement, the infeed of electricity generated from RE results in a reduced demand on the spot market (when the latter is not traded on the energy exchange market, see Felder, 2011). In this context, one should note that the demand for electricity is relatively inelastic with respect to changes in prices (at least in the short term – this corresponds to a steep demand curve, as depicted in Figs. 1 and 2; see also Sioshansi, 2008).

2.2. A Review of the literature

There is an ongoing heated debate on whether energy-only markets offer sufficient economic incentives to permanently ensure a stable electricity supply. Elberg et al. (2013), Cramton, Ockenfels (2012) and Joskow (2006) claim that the energy-only market can fail due to a very price-inelastic demand. They point out that the vast majority of customers are not "smart metered" (i.e. not using a time-of-use metering