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Electricity markets for energy, flexibility and availability — Impact of capacity mechanisms on the remuneration of generation technologies

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ABSTRACT

Increased shares of Renewable Energy Sources (RES) to fulfill ambitious European policy targets, mothballing or decommissioning of existing units, and absent investments lead to concerns about the system and market adequacy. To restore market adequacy, capacity mechanisms (CMs) are widely discussed and implemented in various types. They are intended to provide sufficient and clearly perceivable long-term price signals for available capacity. As integral part of the market, CMs interact with the other markets. Markets like day-ahead markets are used to trade energy. Imbalance markets or reserve requirements are examples for markets for flexibility. Among others, green certificates are in place to value emission-neutral injection from RES. Resulting altered prices and shifting remuneration have effects on all generation technologies. CMs may affect participating technologies by imposing a capacity demand. A resulting change in the generation mix may also have an impact on non-participating technologies. Two gaps can be identified in the discussion and modeling of CMs in the literature. First, proposed game-theoretic equilibrium models fall short in representing the distinctive features of different types of CMs. Second, most models incorporating CMs found in the literature only focus on the interaction with the energy-based market. Valid assessments of CM need to consider the interaction of remuneration for available capacity and flexibility, and the indirect interaction with the remuneration for emission-neutral RES. Two formulations of a game-theoretic market equilibrium model are proposed which represent specific CMs with its distinctive features, in particular a market-wide centralized capacity market (cCM) and targeted strategic reserves (SRs). Moreover, the equilibrium models explicitly combine the CMs with markets for flexibility and indirect with remuneration for RES. We contribute to the discussion of CMs by quantifying the interactions and shifting shares of remuneration. Based on the interaction between CMs and remuneration for emission-neutral injection, the effect of CMs on non-participating RES is described. We conclude based on the case study results that targeted mechanisms, like SRs, implemented with the single purpose of ensuring availability introduce large inefficiencies in the system by missing on the interaction between availability and flexibility. In contrast, a market-wide cCM provides a beneficial outcome for all technologies. At the same time, it yields a sufficient high reserve margin at lowest cost. It provides clear signals for the different values of energy-output, flexibility, availability and emission-neutral injection.

1. Introduction

Due to the ambitious European policy targets for the reduction of greenhouse gas emissions, a strong increase in the installed RES capacity is expected (European Commission, 2014; European Parliament and Council of the European Union, 2009b,a). Particularly, the share of intermittent RES with near-zero marginal costs, such as wind turbines and solar PV panels, is expected to increase significantly. A large-scale integration of these intermittent RES has significant consequences for the remuneration of both existing and newly planned conventional generating units (Green, 2006). First, the number of operating hours of conventional generators is reduced, which implies that the fixed costs must be recovered during fewer operating hours. In addition, electricity prices are pushed downwards and become less predictable (Batlle et al., 2012; Würzburg et al., 2013). As a result, mothballing and decommissioning of existing units are observed in European markets, while investments in conventional power plants remain absent (International Energy Agency, 2015). This leads to concerns regarding

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long-term generation adequacy. Generation adequacy is defined as the availability of generating capacity to meet both base and peak demand (Eurelectric, 2006). In addition, generation adequacy implies the flexibility to follow sharp increases and decreases of the residual load (Brijs et al., 2016).

Long-term security of electricity supply must come from incentives and price signals. To ensure long-term generation adequacy, generation companies must be given sufficient incentives to provide both the required firm capacity and the required flexibility. These incentives should be based on market price signals. In this regard, the term market adequacy is used to describe the ability of the markets to facilitate the link between generators and demand.

In the literature, two distortions of this market adequacy are discussed (Newbery, 2015). The price signals provided by the markets can either be insufficient, which is referred to as missing money (Joskow, 2008) , or the price signals can be perceived as inadequate by the investors, which is referred to as missing market (Newbery, 1989). In order to correct these distortions, capacity mechanisms (CMs) have been proposed to complement current markets. As such, these CMs should provide an adequate long-term price signal by remunerating firm capacity (Cramton et al., 2013) and ensure generation adequacy by setting a minimum capacity demand (De Vries and Ramirez Ospina, 2012). Recently, different types of CMs have been implemented in a number of countries. Examples include the SRs introduced in Belgium (Höschle and De Vos, 2016) , the capacity obligations implemented in France (RTE, 2014) and the centralized capacity market in Great Britain (GB) (Newbery and Grubb, 2015). An extended description of the CMs implemented worldwide is provided in Doorman et al. (2016). As an integral part of the market, these CMs interact with other markets (e.g., the markets for electric energy and the markets for ancillary services) and with policy measure such as support schemes for RES.

The interaction between the energy market and the market for flexibility is typically assessed with models using a high temporal resolution. Such models co-optimize short-term economic dispatch and reserve requirement to minimize system costs (see e.g. Bruninx et al. (2016), van Stiphout et al. (2016)). Moreover, the interaction between the markets for energy and firm capacity (i.e., CMs) is typically assessed in dedicated models. In this regard, different types of models have been used. Two types can be highlighted. First, system dynamics models are models that rely on the description of interactions between states and transitions, hereby focusing on positive or negative feedback loops. Second, agent-based models are used. One can distinguish between a more rule-based approach with sequential decision-making of agents based on certain events or expert rules, and models based on algorithmic game theory resulting in market equilibrium models. The latter is used in this paper. A detailed discussion of the model types can be found in Section 2.1.

Two gaps can be identified in the models used to analyze the impact of CMs. First, these models typically use a highly stylized representation of CMs, i.e., the CM is represented by adding a constraint imposing a minimum level of firm capacity. As such, these models do not allow to represent different types of CM, and analyze their different impact on the different market participants. Second, the models incorporating CMs found in the literature only focus on the interaction between the CM and the energy market. However, a detailed assessment of the impact of CMs on the different market participants must also incorporate the interaction with the markets for flexibility, and policy measures.

The contribution of this article is twofold. First, a game-theoretic market equilibrium model is proposed with a detailed representation of different types of CMs and their distinctive features. Two types of CMs are considered here:

(i) A market-wide centralized capacity market (cCM) is modeled with an accurate representation of the piecewise-linear inverse demand curve for capacity. Such a demand curve is for example implemented in the capacity auction in GB or the Forward Capacity Auction of the ISO New England, USA.
(ii) A targeted strategic reserve (SR) is modeled that takes the contracted capacity out of the market and is only operated upon non-clearing of the energy-based market. Contracted capacity solely serves the purpose of being available during this scarcity events. Such a SR is for example implemented in Belgium.

Second, the presented equilibrium model explicitly combines different markets and policy measures. In the presented case study, the markets for energy and reserves and a complementary CM are included. In addition, a market for green certificates is introduced as an exemplary policy measure.

Based on these models, we contribute to the discussion of CMs by quantifying the varying effect of CMs on the remuneration of participating and non-participating generation technologies. The effect of a CM is linked to the imposed capacity demand and also occurs due to changes triggered by altered revenues and their impact on cost recovery.

The remainder of the article is structured as follows. Section 2 situates the proposed equilibrium model with respect to other models found in the literature that are used to analyze the impact of CMs. Section 3 discusses the case study results and highlights the described interactions. Section 4 concludes the findings of the article.

2. Market models and capacity mechanisms

2.1. Modeling electricity markets with multiple services

Market models for electricity markets are commonly used for both long-term planning purposes and for making short-term dispatch decisions. While short-term economic dispatch models focus on a precise representation of technical characteristics of available generation technologies, long-term planning models focus on investment decisions. In recent literature, planning models close this gap and incorporate more and more operational constraints. The importance of operational aspects in long-term planning models is highlighted in Poncelet et al. (2016a).

State-of-the art operational models rely on stochastic programming techniques for modeling flexibility needs. However, most operational models still include deterministic reserve requirements (Bruninx et al., 2016). van Stiphout et al. (2016) propose a long-term planning model that incorporates detailed reserve requirements to capture flexibility. Both types of models are capable to describe flexibility needs. However, they overlook specific markets for available capacity such as CMs.

Opposed to optimization models with a central planner perspective, game-theoretic models introduce selfishly optimizing agents in a market context. Under the assumption of perfect competition, such market equilibrium models may result in a Nash Equilibrium (NE). Examples of such market equilibrium models found in literature address availability by adding a minimum constraint for capacity. This is a simplification to represent a CM (Ehrenmann and Smeers, 2011; Gürkan et al., 2013; Özdemir, 2013). Höschle et al. (2015, 2016) introduce specific market equilibrium model formulations for different CMs in one or multiple interconnected zones. At the same time, operational details are introduced with an hourly time resolution. The presented approaches enable to capture the design differences of CMs. In this article, these state-of-the-art models are further expanded. In addition, the detailed CM models are combined with market models for flexibility and emission-neutral RES. Meyer and Gore (2015) establish another equilibrium model for two connected