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The effectiveness of capacity markets in the presence of a high portfolio share of renewable energy sources

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A B S T R A C T

The effectiveness of a capacity market is analyzed by simulating three conditions that may cause sub-optimal investment in the electricity generation: imperfect information and uncertainty; declining demand shocks resulting in load loss; and a growing share of renewable energy sources in the generation portfolio. Implementation of a capacity market can improve supply adequacy and reduce consumer costs. It mainly leads to more investment in low-cost peak generation units. If the administratively determined reserve margin is high enough, the security of supply is not significantly affected by uncertainties or demand shocks. A capacity market is found to be more effective than a strategic reserve for ensuring reliability.

1. Introduction

In this research, we analyze the effectiveness of a capacity market in the presence of a growing share of intermittent renewable energy sources. The European Union (EU) is at the forefront of the renewable energy transformation. The increasing reliance on electricity generation from variable renewable energy sources (RES) has led to concerns regarding the security of supply. The missing money problem and other vulnerabilities of the electricity markets due intermittent renewable energy resources in the supply mix have been extensively discussed in the literature (Borenstein et al., 1995; Brown, 2001; Pérez-Arriaga, 2001; Stoft, 2002; Woo et al., 2003; Joskow, 2006; De Vries, 2007; Bhagwat, 2016).

Concerns about the security of supply can be addressed by implementing capacity mechanisms to ensure adequate investment in generation capacity. These are sometimes considered as a means of providing stability during the transition to a decarbonized electricity system. A capacity market is a quantity-based mechanism in which the price of capacity is established in a market for capacity credits. In a capacity market, consumers, or agents on their behalf, are obligated to purchase capacity credits equivalent to the sum of its expected peak demand and a reserve margin. Capacity credits can be allocated in auctions or via bilateral trade between consumers and producers (Cramton et al., 2013; Rodilla and Batlle, 2013). The reserve margin requirement is expected to provide a stronger and earlier investment signal, thereby ensuring adequate generation capacity and more stable electricity prices. Capacity markets have been discussed extensively in literature such as: Hobbs et al., 2001; Stoft, 2002; Joskow, 2008; Chao and Lawrence, 2009; Cepeda and Finon, 2011; Rose, 2011; Cramton et al., 2013; Finon, 2013; Mastropietro et al., 2015; Meyer and Gore, 2015; Höschle and Doorman, 2016; Bhagwat, 2016; Bhagwat et al., 2016a,b, 2017; Bothwell and Hobbs, 2017; Bushnell et al., 2017; Höschle et al., 2017.

In the literature, several types of computer models have been used to study capacity markets. Hach et al. (2015), Cepeda and Finon (2013) and Petitet et al. (2017) use a system-dynamic approach. Moghanjooghi (2016) uses probabilistic model. Botterud et al. (2002), Doorman et al. (2007), Dahlan and Kirschen (2014), and Mastropietro et al. (2016), use an optimization modeling approach. Ehrenmann and Smeers (2011) use a stochastic equilibrium model, while a partial equilibrium model is used by Traber (2017).

In the existing research, capacity markets are modeled without sufficient granularity to understand the operational dynamics of

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these policy constructs and to compare different capacity mechanism designs. Moreover, none of the reviewed studies considered the combined effects of uncertainty and path dependence on the development of electricity generation portfolios with a growing share of RES. In reality, the ability of investors to make decisions is bounded and may lead to myopic investment decisions and consequently, suboptimal achievement of policy goals.

The use of an agent-based modeling approach allows us to study the development of the electricity market under imperfect information and uncertainty. Moreover, the use of EMLab-Generation allows higher granularity in modeling the capacity market. This work also extends the research on the effectiveness of capacity markets in providing reliability in the presence of demand shocks resulting in load loss and a growing share of renewable energy in the supply mix.

In the next section, we describe the EMLab-Generation model and its implications for implementing capacity markets. Section 3 describes the scenarios that we use. In Section 4, we present the results from our simulation of a capacity market implemented under various conditions. The conclusions are summarized in Section 5.

2. Model description

2.1. EMLab-generation

EMLab Generation is an open-source agent-based model of interconnected electricity markets that was developed with the aim of analyzing the impact of various carbon, renewable and adequacy policies on the long-term development of electricity markets. EMLab-Generation model was developed at Delft University of Technology.

Agent-based modeling utilizes a bottom-up approach in which key actors are modeled as ‘agents’ that make autonomous decisions, based on their interactions with the system and other agents in the model (Dam et al., 2013; Farmer and Foley, 2009). The advantages of using ABM in modeling complex socio-technical systems has been discussed (Chappin, 2011; Dam et al., 2013; Helbing, 2012; Weidlich and Veit, 2008). In the context of electricity markets, ABM captures the complex interactions between energy producers and a dynamic environment. No assumptions regarding the aggregate response of the system to changes in policy are needed, as the output is the consequence of the actions of the agents.

The main agents in this model are the power generation companies. They make decisions regarding bidding on the electricity market, investing in new generation capacity and dismantling existing power plants. Their decisions are based on factors endogenous to the model (such as electricity prices) as well as exogenous factors (such as different policy instruments, fuel price trends, and electricity demand growth trends). As the model is designed to analyze the long-term development of electricity markets, the simulation is run for a period of several decades, with a one-year time step.

Power-plant investment decisions are based on expected net present value. There are 14 different power generation technologies available for the agents to choose from in the model. The attributes of the power generation technologies, such as operation maintenance (O&M) costs and fuel efficiencies, are based on data from IEA World Energy Outlook 2011, New Policies Scenario (IEA, 2011). The assumptions regarding the power generation technologies are presented in Table 3 of the Appendix.

Electricity demand in the model is represented as a load-duration curve developed which is based on empirical data and approximated by a step function with multiple segments of variable length (Fig. 1). The advantages of using the load-duration curve approach in this model are described in (Richstein et al., 2014). In this model demand is inelastic to price.

The government sets annual targets for electricity generation from RES. In case the competitive generation companies do not invest enough in RES to meet the government target, a specific renewable energy investor will invest in the additional RES capacity needed to meet the target RES capacity, regardless of its costs. This way, the current subsidy-driven development of RES capacity is simulated. The variability or intermittency of renewables is approximated by varying the contribution of these technologies (availability as a percentage of installed capacity) to the different segments of the load-duration function. The segment-dependent availability of RES is varied linearly from a high contribution to the base segments to a very low contribution to the highest peak segment. (See Table 3 in the Appendix). A detailed description of how intermittency is modeled is available in De Vries et al. (2013) and in Richstein et al. (2015a, 2015b, 2014).

The power companies make price-volume bids for all power plants in their portfolios for each segment of the load-duration curve. The bids equal the variable cost and the available capacity of the underlying power plants. The electricity market is cleared for every segment of the load-duration curve in each time step. The market price for each segment is set by the highest clearing bid. If the supply is lower than demand, the clearing price for the segment is set to the value of lost load (VOLL). This causes high price volatility; demand elasticity would dampen prices, which in turn might reduce the propensity toward investment.

We consider an isolated electricity market (without interconnections). A detailed description of this model is available online in the EMLab-Generation technical report[1] and other previously published work (De Vries et al., 2013; Richstein et al., 2015a, 2015b, 2014; Chappin et al., 2017).

2.2. The capacity market module

The capacity market module in EMLab-Generation is a simplified representation of the NYISO-ICAP capacity market. We chose this for its relatively simple design, because it was one of the first capacity markets and because it is arguably meeting its policy goals. It is projected that no new resources would be required in the NYISO region till 2018 (Newell et al., 2009).

We start our description with the consumer side. Load-serving entities are obligated to purchase the volume of unforced

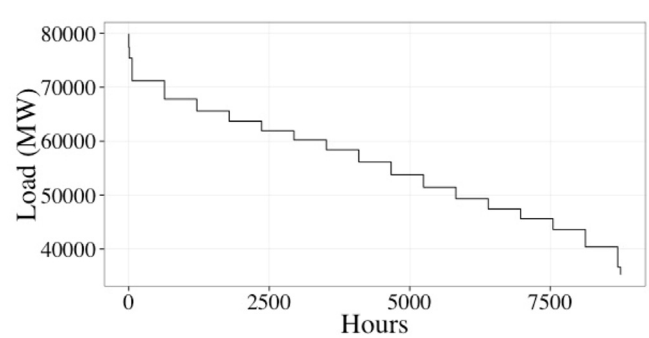

Fig. 1. Load-duration curve in EMLab-Generation for one country.

[1] www.emlab.tudelft.nl.

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