Interaction between Security of Supply and Investment into Renewable Energy in the Netherlands and Germany

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Abstract

We study the potential effects of introducing a capacity market in a European country in response to the deteriorating market position of many (mainly gas) generators due to the growing share of renewable energy. We pay specific attention to cross-border effects of capacity markets, because security of supply in Europe is an issue of subsidiarity and is therefore tackled at the national level. Germany has introduced a small strategic reserve to handle the consequences of the nuclear phase out. Other European countries such as France and the UK are in various stages of implementing a form of the capacity market. A capacity market ensures generation adequacy by addressing the missing-money problem through a separate market for tradable capacity credits. While the issue of security of supply is being addressed at the national level, the European Commission has set highly ambitious goals for generation from renewable energy resources at a pan European level. It is legally binding on each of the member states through their respective National Renewable Energy Action Plans (NREAPs) which impose targets for electricity generation from renewable sources per member state.

The support of RES is directly linked to this issue of security of supply, since the promotion of RES displaces the merit order of conventional technologies on spot markets. The displacement of the hourly merit order implies a lower load factor, lower average revenues, and lower predictability of their revenue due to intermittency of RES. Given such a setting, it is pertinent that the long term interactions between such aforementioned policies are analysed. Here, we study the impact of two policies applied simultaneously: 1) the security of supply instrument, the capacity market, 2) target investment into renewable energy for both a single country scenario and a scenario where it is interconnected with an energy only market.

1 Introduction

There is increasing concern that energy-only markets are inadequate when it comes to ensuring generation adequacy in the power sector over the long term. This is reflected in the fact that several Independent System Operators have commissioned studies about security of supply over the last few years; OFGEM and CEER (Council of European Energy Regulators) are some of them. There is some empirical evidence and substantial theory [?] as to why incentives for investments are insufficient in such markets. Capacity mechanisms are policy tools that aim at providing incentive to this investment into reliability both over the long-term and short-term.

Capacity mechanisms are of several types. While some are price-based instruments, such as capacity payments and operating reserves pricing, others are quantity-based instruments, such as capacity markets and reliability contracts []. Price-based instruments, as the name suggests, regulate reliability based on price, while quantity based instruments regulate based on volume. Their performance objectives are manifold.
The primary objective is to provide incentives for generating companies to ensure long term reliability, i.e., sufficient investment in generating capacity. The scope of this work is limited to quantity based mechanisms such as capacity markets.

Compounding this inadequacy of energy-only markets is the expected change in the composition of the generating portfolio over the coming decades. It is expected that the European electricity industry is almost entirely carbon free by 2050. The promotion of RES displaces the merit order of conventional technologies on spot markets. While it is partly because of priority access that RES generators avail of in many countries, this issue of displacing of merit order would exist even without priority access due to the low marginal costs of RES. This has significant consequences on the investment behaviour of conventional energy generators. The displacement of the hourly merit order implies a lower load factor, lower average revenues, and lower predictability of their revenue due to intermittency of RES. In addition, implementation of a capacity market in a country in highly interconnected Europe might show cross border effects that need further insight and understanding.

The purpose of this work is to evaluate capacity markets, a type of capacity mechanism, in its ability to ensure long term generation adequacy in interconnected western Europe, significant investment into renewable electricity sources (RES) is to be made, as per the NREAPs. The effectiveness of capacity markets are assessed primarily on the following indicators: performance of the electricity market (adequacy of supply, stable energy prices), consumer welfare and producer welfare. This work is part of a larger project at the Energy and Industry section of TPM, EMLab Generation, which is focused on studying the electricity market in transition towards a low-carbon regime. The methodology applied to carry out this research is agent based modelling. A model of the capacity market has been built and analysed.

This paper comprises of the following sections - section 2 provides a brief insight into the problem of security of supply, and the concept of capacity markets, their implementation and their performance so far. It also comprises of a section on the choice of methodology. This is followed by an introduction to the electricity model, the conceptual model of the capacity market, the modelling of the renewable energy production. Subsequently the results are presented and discussed.

2 Literature Review and Methodology

2.1 Energy-only markets and their shortcomings

Energy-only markets are so termed to indicate that the price of electric energy is the only determinant of capacity investment. This section outlines the main issues with energy markets as is, and then outlines how the problems are compounded by the transition of the power sector towards a low-carbon regime. From literature, the following ideas comprise of the main inadequacies of energy-only markets.

- High price volatility
- Insufficient demand response.
- Reliability and stability are public goods that will not be provided by market, and hence has to be administratively ensured.
- Actions taken by system operators, specifically non-price rationing of demand, impose social costs that are not reflected in the market prices, such as reducing system voltage by 5% to reduce demand
- Reliance on bilateral out-of-market contracts to avoid rolling blackouts or network collapse.
- Another aspect of social costs incurred on the consumer is the asymmetry between costs of over-capacity versus the cost of under-capacity. A blackout or network collapse costs the society a lot more than the cost of having over-capacity. This is referred to as the asymmetric loss of welfare function.
- Opportunities to exercise market power.

Problems with energy only markets have been popularly characterised as the missing money problem, first termed so by Cramton and Stoft (2006). The idea is that the last increment in generating capacity, which is
standing in reserve to meet low probability, high demand contingencies, must earn all their revenues during a few critical hours, with price spikes. Therefore the prices of ancillary services must be quite high in an energy only market. If the prices are too low, there will be underinvestment in generating capacity.

2.2 The Alternative: Among Others, the Capacity Market

As a consequence of generation adequacy problems of energy-only markets, several solutions, referred to as ‘capacity mechanisms’, have been implemented across the world. Most of them involve an attempt at some form of regulation of ‘reliability’ as a good. This regulation can be broadly characterised as either price based or quantity based. Why such a distinction is relevant is a fundamental issue that has been addressed by Weitzman [5].

Price Based Incentives Price based incentives, as the name indicates, regulates the reserve capacity through an administratively determined price. Capacity payments are one of the oldest solutions that were used. Strategic reserves and operating reserves are other such mechanisms that have been implemented. Refer to Kaveri Iychettira/ other references for further details.

Quantity Based Incentives By such policy instruments the quantity of the resource is administratively set, and the price is left to the market participants. An advantage of this method, in the context of generation adequacy is that a robust reserve margin of capacity is maintained. Several forms of quantity based incentives have been implemented by independent system operators (ISO) in several regions in the USA, Latin America, and Australia. In Europe, the implementation of a capacity certificate system is underway in France while the UK is in an advanced stage of policy design of a forward capacity market. The following is a description of a capacity market, with special focus on the ICAP market at NYISO. This paper focuses on the NYISO:ICAP as it implements a simple market design with no forward capacity requirement. Further, the capacity market seems to be performing as intended, as projections show that no new resource requirements are necessary till 2018.

2.2.1 Capacity Markets, with special focus on NYISO

While the fundamental principle remains the same, implementation of the capacity market has been significantly different across ISOs. While some regulators mandate consumer’s participation in centralized capacity markets to meet capacity obligations, others allow simply for reliance on bilateral contracts or even self supply. Some markets offer capacity credits, while others organize a ‘reliability options’ system.

In a centralized capacity market, like at NYISO ICAP, a reserve requirement is imposed and the market is administered by the system operator who facilitates capacity transactions between market participants [6]. This design mainly mandates a reserve requirement, determined by the system operator, together with a centralized capacity market, also administered by the system operator. Such an arrangement does not preclude the possibility that market participants meet their obligations by self supply or bilateral contracts. The capacity market becomes a sort of residual market for settling uncommitted resources and unsatisfied obligations.

Reserve requirements may be set even without organising centralised capacity markets. However, exclusive reliance on self provision or bilateral arrangements could result in limited liquidity and transparency of the market. Further, smaller LSEs face higher transaction costs. Centralized capacity markets facilitate efficient bilateral transactions by providing a transparent price and standardized capacity product. It also allows for market monitoring, by creating information necessary to mitigate market power.

NYISO: ICAP The New York Independent System Operator (NYISO) organises the installed capacity (ICAP) market, where an obligation on placed on load serving entities to procure ICAP to meet minimum reserve requirements in a certain region (refer NYISO website). Auctions are locational, which means that transmission congestion is accounted for. It incorporates the following main features:

- The Installed Reserve Margin (IRM) is established annually by an independent council, NYSRC, which
requires that the loss of load expectancy (LOLE)\(^1\) must on average be no more than once in 10 years. The minimum installed capacity requirement is calculated in megawatts as a product of the forecast peak load and the quantity one plus the IRM \(^2\).

- Three types of ICAP auctions are carried out: Capability period (Strip) auctions, monthly auctions, and spot market auctions. The first two kinds of auctions are two sided, they include bids to purchase from LSEs and offers to sell from qualified capacity providers. The spot auctions comprise of supplier bids being cleared against predetermined, sloping demand curves.
- The slope of the demand curve is determined by two points: a) the cost of new entry (in \$kW-month) and b) the point where price of additional capacity is zero.

The following section provides a description of the methodology used for this research. It also comprises of a description of the existing EMLab model, to which the capacity market based on the NYISO ICAP model has been built as an extension.

3 Methodology and Model Description

3.1 Agent Based Modelling

Agent based modelling is a bottom up approach in which actors are modelled as agents who make decisions \(^3\). A certain system is suitable for modelling using ABM if the following conditions are satisfied \(^4\).

- The problem is of a distributed nature; each actor is autonomous to some extent.
- The agents (subsystems) operate in a highly dynamic environment.
- The interaction in the subsystem is characterised by flexibility: it can result from a reactive or pro-active attitude, from a propensity to co-operate or to compete.

Each of the above conditions are satisfied for the modelling of an electricity market - the agents, i.e., energy producers are autonomous decision makers. The energy producers do operate in a highly dynamic environment, where past decisions affect actions in the present. And the interaction arises from a propensity to compete.

Market Dynamics and Complexity  A comprehensive review by Weidlich and Veit \(^5\) of agent based modeling applied to electricity market models reveals issues, knowledge gaps, and methodological drawbacks commonly noticed in such literature. Although agent based modelling is well poised to handle complexity, a lot of research is done by simplification of the real world significantly. For instance, in EMLab generation, the consumers are only modeled as one aggregate entity having a demand. In the capacity market model, therefore the demand side would be similarly simplified. Most studies do not consider out of equilibrium dynamics, or the circumstances under which agents reach an equilibrium. This could be a feature for consideration in the capacity market model analysis.

3.2 EMLab Generation Model

EMLab-Generation model is an agent-based model with as purpose to explore the long-term effects of interaction between energy and climate policies in the electricity sector \(^6\). The model is based within the AgentSpring framework which is an agent based modelling and simulation framework based on Spring and Neo4j, a powerful graph database. As this model explores the long term impacts of interacting energy and climate polices, each time step in the model is of one year. Further, the fuel price and demand uncertainty is incorporated by altering these parameter over many runs in Monte Carlo fashion. The main agents in

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\(^1\)The LOLE, i.e., the probability of disconnecting firm load due to a resource deficiency. This is after allowance for scheduled and forced outages and forced deratings or brownouts.\(^2\)

\(^2\)Capability periods recognize seasonal variations, one for the summer (May 1 to October 31) and one for the winter (Nov 1 to April 30). One capability year then comprises of two capability periods.
the EMLab-Generation model are the energy producers. These agents operate in an environment with a combination of policies in either a single region or in two interconnected regions.

The energy producers make decisions in new capacity, dismantling of old unprofitable power plants, electricity bids on the market and bids on the carbon market. The key drivers of change in this model are policy instruments, the fuel price and electricity demand scenarios. The results from this model are based on the combined effect of the actions the agents and their interactions with each other and the surroundings.

The investment behaviour of the energy producers depends primarily on the attractiveness of investment based on the net present value of new plant. The generator dispatch is dependent on the demand, fuel prices, electricity and CO2 prices and the fuel efficiency of generators [11]. The model provides thirteen power plant technology options to the generator. The development of different technologies in the model is incorporated by the gradual change in costs and parameters such as efficiency for every time step. The power plant technologies have been modelled based upon IEA World Energy Outlook 2011 New Policies Scenario [12].

The electrical demand is represented by a load duration curve in the form of a step function of 20 segments of variable lengths approximated from load data. At every time step, the electricity markets are cleared for each segment of the load duration curve. In the carbon market there is a single annual CO2 price. The use of this load duration curve leads to short run times and acceptable time frames for running large number of Monte-Carlo simulation runs. The market clearing process is carried out each segment of the load duration curve. In this process the price-volume bid pairs submitted by the generators for each of their power plants are sorted in a descending order by price. The market clearing price for each segment is determined by the intersection of the demand and supply functions in that segment. If the available supply in the market is lower than demand, the market clearing price is set to the value of lost load. A much more detailed description of the model can be found in the report, ‘Decarbonisation of the Power Sector’ [11].

4 Conceptualisation and Experiment Design
4.1 Model of a Capacity Market

The capacity market model comprises of the following processes. The demand curve is predetermined by the regulator, by forecasting the demand for the current year and then augmenting it by a predetermined reserve margin. All energy producers then submit their bids into the capacity market. The simulation of market clearing is identical to a uniform price clearing auction. The payments are then made, and finally, the expected revenues from the capacity market, if applicable, are incorporated into the investment decisions. In a two node system, only generators who are located in the market with the capacity mechanism are allowed to participate in the capacity market. Each of the steps of the algorithm are described in greater detail below.

Forecasting Demand Curve An independent regulator agent is created for each zone. The reserve margin (r) is set exogenously as a property of the regulator. The peak demand for the current year is forecasted by the regulator, by extrapolation of past values of demand using geometric trend regression. The targeted demand is computed as the peak forecast demand augmented by the reserve margin. It specifies the minimum installed capacity requirement for the region, referred to hereafter as demand target (D’t), and is computed as follows

\[ D_t = V_{peak} \times (1 + r) \]  

(1)

Submitting Bids The energy producers bid into the capacity market by submitting bid prices and quantities for each of his power plants that are located in the zone with the capacity market. The bid price is marginal cost of capacity, rather than energy. For an energy producer, this amounts to the fixed operation and maintenance of a power plant, offset by net revenues from the electricity spot market. If the net
electricity spot market (ESM) revenues are greater than the fixed operation and maintenance cost of the
power plant, the energy producer bids at zero price. However, if the net ESM revenues are less than the
fixed operation and maintenance cost of the power plant, the difference amounts to the bid price. It must
be noted that no strategic behaviour has been modelled. The energy producers simply bid based on each of
their costs and revenues. The capacity of the bid is determined based on the availability of the plant only in
the peak segment, and not the nominal capacity of the power plant. This way, plants running on renewable
energy technologies submit only partial capacities into the market.

Market Clearing The clearing of the market involves a one-sided bidding process as the demand curve
is predetermined, this simulates the regulator bidding on behalf of the load serving entities. The demand
curve is determined as follows.

Demand Curve In the capacity market model, an abstract version of the demand curve employed in PJM
and NYISO is implemented. The demand curve in the model is a sloping demand curve, as shown in figure
[1]. The sloping demand curve stabilizes market prices because any movement along the demand curve results
in relatively small price changes, consequently allowing for fewer opportunities for market manipulation [6].
The figure [2] illustrates this. The demand curve is made up of two line segments: a horizontal line segment
at the price cap ($P_{\text{cap}}$), up to point $a$. The price cap is set as in NYISO, equal to 1.5 times the estimated cost
per (MW-year) of a new peaking unit, a sloping line segment passing through end points points $a$ and $c$. At
point $a$, price is set at the price cap, while the demand is set at $D_t \times (1 - LM)$, where $LM$ is a fraction of
$D_t$. Point $c$ is at the intersection the demand target at its upper margin (UM) at $D_t \times (1 + UM)$, and the
price at 0. The equation for the sloping demand curve is
demand = \( D' t \times (1 - rLM) + (CP_c - \text{price}) \times (rUM + rLM) \times D_t/CP_c \) (2)

The market clearing is designed simply based on uniform price clearing. The bids are sorted by order of increasing price, and are accepted until the demand is satisfied. A clearing point price (in EUR/MW-year) and volume (in MW) is thus determined. On clearing of the capacity market, all the generating units in the merit order are paid the clearing price for the capacity made available by them. While making investment decisions, the energy producers take into account the possible revenues from the capacity market, by forecasting values based on previous years capacity market prices.

4.2 Targeted Investment into Renewable Energy

There is a section in the investment algorithm which allows for targeted investment into renewable energy. An agent, the renewable energy agent, has been created, who carries out the following function. If private investors do not meet the national (government-specified) target for a specific year the renewable target investor simply invests exactly the missing capacity (MW) regardless of any budget constraints. Both countries therefore implement renewable energy targets according to their individual National Renewable Energy Action Plans (NREAP) [13].

This has been created to simulate a scenario where excess renewable energy forms part of the energy mix. This enables the analysis of market prices, investments in other technologies etc in the presence of substantial amounts of RE capacity.

4.3 Experiment Design

The experiments seek study the impact of two policies applied simultaneously: 1) the security of supply instrument, the capacity market, 2) target investment into renewable energy for both a single country scenario and a scenario where it is interconnected with an energy only market. Therefore the following hypotheses are made.

4.3.1 Hypotheses

**Hypothesis 1** A capacity market, as a policy instrument in combination with targeted investment in renewable energy, ensures generation adequacy in one, isolated country.

This hypothesis tests the effects of two policies: the capacity market, as well as targeted investment in renewable energy on a region modeled over Germany. The targeted investment in renewable energy is based on the National Renewable Energy Action Plan until the year 2020 for the Netherlands [13]. The first ten years of the simulation use the NREAP data until 2020. It then extrapolates that data for the next forty years. With this experiment, we seek insight into how the design of a capacity market might have to adapt in the presence of substantial intermittent energy generation.

1. Experiment one compares the capacity market scenario to the base case scenario in the absence of targeted RE generation.
2. Experiment two compares the capacity market scenario to the base case scenario in the presence of targeted investment into RE Generation.

**Hypothesis 2** A capacity market in country B, as a policy instrument in combination with targeted investment in renewable energy, ensures generation adequacy in country B while it is interconnected with an energy-only market in country A.

Hypothesis 2 explores the cross border effects of a capacity market implemented in Germany, which is interconnected to the energy-only market in the Netherlands, in a scenario where both countries invest in renewable energy generation as per the NREAP plans for the next fifty years. It is interesting to observe
how aspects such as intermittency, risk allocation, price levels, and possibly free-rider behaviour play out in such a scenario.

Again, to test the above hypothesis, experiments 3 and 4 were conducted, one without targeted investment into RE Generation and the other with. The following table briefly presents the experiment design.

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Experiments</th>
<th>Scenario</th>
<th>BaseCase/CapacityMarket</th>
<th>Target RES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothesis 1</td>
<td>Experiment 1</td>
<td>Scenario 1</td>
<td>BaseCase</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Scenario 2</td>
<td>CapacityMarket</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Experiment 2</td>
<td>Scenario 3</td>
<td>BaseCase</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Scenario 4</td>
<td>CapacityMarket</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Hypothesis 2</td>
<td>Experiment 3</td>
<td>Scenario 1</td>
<td>BaseCase</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Scenario 2</td>
<td>CapacityMarket</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experiment 3</td>
<td>Scenario 3</td>
<td>BaseCase</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Scenario 4</td>
<td>CapacityMarket</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

**Market Design Parameters** The values for capacity market design parameters are set as follows:

- **Slope** (as defined in equation 4.1) is Upper Margin (UM) = 0.025, Lower Margin (LM)=0.025
- The reserve margin (r) in equation 1 is = 0.156
- PriceCap= 2*CONE = 2*Fixed Cost Of a CCGT plant = 2*29470 Eur/MW
- The value of lost load for the electricity market is set at 2000 Eur/MWh.
- The interconnector capacity between the two countries in experiments 2 and 3 is set at 4441 MW.

**4.3.2 Performance Indicators**

The Key Performance Indicators with which the effects of a capacity market may be evaluated may be classified by the following themes: electricity market performance, consumer welfare and producer welfare, and importantly, the capacity market performance. For every scenario, key numerical indicators are either the mean or the standard deviation (SD) of the variable. Each scenario has 5000 observations (100*50). For every indicator, the mean is first computed across one run of 50 ticks, yielding a vector of 100 fields. The final mean or SD of the variable is calculated using this vector of means.

For the theme of **electricity market performance** we analyse ‘adequacy’, in terms of a) **Supply Ratio**, the ratio of Total Operational Capacity Per Zone(in MW) to Peak Demand Per Zone (in MW). A value of supply ratio below 1 would clearly indicate a shortage. Another measure for adequacy is the **Loss of Load Expectation (LOLE)**, which measures how long on average the generation capacity is likely to fall short of the demand. We also observe **Average Electricity Price**, and **Electricity Price Volatility**, which is the standard deviation of the average electricity price per tick (year).

For the theme of **consumer welfare**, we observe the variable **Consumer Expenditure**, which encompasses expenses of the consumer in the energy market as well as the capacity market, when present.

While studying impacts on **producer welfare** we look at the variables **Producer Cash** and **Aggregate Profit**. **Producer Cash**: simply measures the cash balance of a producer at each tick. **Aggregate Profit** measures the sum of the profit, that is total revenues minus total cost, earned by each producer in a given zone. Here, total revenues entail revenues from the capacity market and the energy market.

**5 Results**

**Hypothesis 1** A capacity market, as a policy instrument in combination with targeted investment in renewable energy, ensures generation adequacy in one, isolated country.
The single country is based on Germany. To test this hypothesis, two experiments were performed. Experiment 1, the reference case, where the agents (generation companies) invest in renewable energy technologies based primarily on their economic viability. Experiment 2 simulates two scenarios one with the capacity market and the other without, both in the presence of targeted renewable energy generation.

The following figures and table compare the reference case (exp 1) with the RES case (exp 2). The series of figures below 2, 3 and 4 show Supply Ratio in experiment 1 and experiment 2, and Capacity Market Clearing Price in experiment 2 respectively.

### Figure 2: Exp 1: Supply Ratio

<table>
<thead>
<tr>
<th>Time</th>
<th>BaseCase</th>
<th>CapacityMarket</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>10</td>
<td>1.12531</td>
<td>1.207527</td>
</tr>
<tr>
<td>20</td>
<td>1.206611</td>
<td>1.207527</td>
</tr>
<tr>
<td>30</td>
<td>1.206611</td>
<td>1.207527</td>
</tr>
<tr>
<td>40</td>
<td>1.206611</td>
<td>1.207527</td>
</tr>
<tr>
<td>50</td>
<td>1.206611</td>
<td>1.207527</td>
</tr>
</tbody>
</table>

### Table 2: Results of Hypothesis 1

<table>
<thead>
<tr>
<th></th>
<th>Experiment 1 (Reference Case)</th>
<th>Experiment 2 (With RES)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scenario 1</td>
<td>Scenario 2</td>
</tr>
<tr>
<td>AvgElectricityPrice (Eur/MWh)</td>
<td>46.04254</td>
<td>44.27977</td>
</tr>
<tr>
<td>SupplyRatio</td>
<td>1.124518</td>
<td>1.206611</td>
</tr>
<tr>
<td>ConsumerExpenditure (Eur/year)</td>
<td>6.01E+11</td>
<td>6.62E+11</td>
</tr>
<tr>
<td>ProducerCashSum (Eur/year)</td>
<td>3.60E+11</td>
<td>4.31E+11</td>
</tr>
<tr>
<td>LOLE(inHours)</td>
<td>4.223119</td>
<td>1.272479</td>
</tr>
<tr>
<td>PercentageChangeProducerCash</td>
<td>-25.7098</td>
<td>10.56298</td>
</tr>
<tr>
<td>CapacityPrice(Eur/MW-year)</td>
<td>40124.27</td>
<td>41894.06</td>
</tr>
<tr>
<td>CapacityVolume(MW)</td>
<td>99715.63</td>
<td>98805.27</td>
</tr>
<tr>
<td>ShortageCM(%)</td>
<td>0.234872</td>
<td>0.2042</td>
</tr>
</tbody>
</table>

**Observation** To look at the effects of targeted investment in RES alone, we compare scenarios (data columns) 1 and 3 in table 2.

- When RES is introduced in scenario 3, the average electricity prices are lesser by 11% (from 46.0 Eur/Mwh to 40.9 Eur/MWH) as compared to scenario 1. However, the standard deviation (SD) of the average electricity prices for the scenario with RE is also much higher. The supply ratio is also
Figure 3: Exp 2: Supply Ratio

reduced from 1.12 to 1.07 in the presence of renewables. Importantly, the loss of load expectation (LOLE) increases three fold, from about 4 hours per year to 12 hours per year on average.

- The consumer expenditure is lesser in the RES scenario by 14%. Percentage Change in Producer Cash is an indicator of the change in producers’ cash at the end of the fifty years, relative to their cash position at the start (year 1). We see a sharp decrease in producer cash in the scenario 3 (with RES).

Here, we observe the impact of the introduction of the capacity market by comparing columns 1 and 2 with columns 3 and 4.

- In both experiment 1 (reference case) and experiment 2, we see that the capacity market impacts parameters similarly - the average electricity price is lesser by 3.8% in experiment 1 and by 3.3% in experiment 2. The supply ratio, increases by about 7% in experiment 1 and by 12% in experiment 2.

- The LOLE drops in both experiments, but the drop is much greater in experiment 2. The mean level of LOLE in the scenario with the RES and the capacity market (scenario 4) is much lesser than that in scenario 2.

**Interpretation**

- Targeted investment in RE causes the electricity prices to reduce on average. This is not unexpected, given that the marginal costs of RES technologies are negligible. In addition, the increased volatility in electricity prices is also a result of the intermittency from the RES. There is a drop in the supply ratio, which indicates that there is reduced adequacy in the presence of renewables. The LOLE i.e., the probability of outages in scenario 3 is three times higher, that can also be explained by the intermittency of renewables.

- The consumer expenditure reduces significantly due to the reduced electricity prices.

- Producer cash drops drastically - this is an artifact of the simulation, where the target investor for RE is designed in a way that the target amount of RE capacity is invested in irrespective of budget constraints. And producer cash, being an aggregate measure for all producers, includes the balances of the target investor and shows the anomaly.

With the Capacity Market

- In both experiments the capacity market works as expected - the supply ratio is increased to maintain the reserve margin, the average electricity prices reduce, the probability of outages also reduce. It
could even be argued that the capacity market functions slightly better in the scenario with the RES as compared to the reference case.

- The main point to be noted is that the intermittency due to RES makes the case for the capacity market much much stronger.

**Conclusion** The two main conclusions are that firstly intermittency (probablility of outages) increases almost three fold, if the NREAP targets were to be met in the next 50 years, and secondly, that a capacity market effectively remedies the situation by ensuring sufficient investment in peak capacity. It is interesting to note that a design of a capacity market is quite robust in that no design changes are necessary for the capacity market to achieve the same degree of reliability as in the no RES (reference) case.

**Hypothesis 2** A capacity market in Germany, as a policy instrument in combination with targeted investment in renewable energy, ensures generation adequacy in Germany while it is interconnected with the Netherlands.

The electricity markets of the two counties are interconnected with an interconnector capacity of 4441 MW and there is market coupling between the two countries.

The capacity market scenario implements the capacity market policy in Country B again, while Country A remains an energy-only market. Both countries implement renewable energy targets according to their individual National Renewable Energy Action Plans.

The main results of the simulation are presented in the following figures and tables.
Figure 5: Exp 4: Supply Ratio, Germany

Figure 6: Exp 4: Supply Ratio, Netherlands
Figure 7: Exp 4: Capacity Market Clearing Price

Table 3: Results of Hypothesis 1

<table>
<thead>
<tr>
<th>Experiment 3 (Reference Case)</th>
<th>Experiment 4 (With RES)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scenario</strong></td>
<td><strong>Scenario</strong></td>
</tr>
<tr>
<td></td>
<td>Without CM</td>
</tr>
<tr>
<td>AvgElectricityPriceDE</td>
<td>64.7506782</td>
</tr>
<tr>
<td>AvgElectricityPriceNL</td>
<td>70.2175827</td>
</tr>
<tr>
<td>SupplyRatioDE</td>
<td>1.12395655</td>
</tr>
<tr>
<td>SupplyRatioNL</td>
<td>1.14354159</td>
</tr>
<tr>
<td>ConsumerExpenditureNL</td>
<td>1.5152E+11</td>
</tr>
<tr>
<td>ProducerCashSumMean</td>
<td>1.174E+11</td>
</tr>
<tr>
<td>AggregateProducerProfit</td>
<td>5.141942435</td>
</tr>
<tr>
<td>OutagesinHoursDE</td>
<td>3.75</td>
</tr>
<tr>
<td>OutagesinHoursNL</td>
<td>7.9676</td>
</tr>
<tr>
<td>CapacityPrice</td>
<td>39195.71</td>
</tr>
<tr>
<td>CapacityVolume</td>
<td>100343.7</td>
</tr>
<tr>
<td>ShortageCM</td>
<td>0.3002</td>
</tr>
</tbody>
</table>

**Observations**

- The effect of targeted RES is evident, much like under hypothesis 1, in the average electricity prices, in the LOLE values (probability of outage) etc. Comparing scenario 1 and scenario 3, we observe much more pronounced effects relative to the single country scenario: here, the average electricity prices reduce by 25% in Germany and by 27% in the Netherlands.
- In experiment 3, the supply ratio in Germany shows an increase in the capacity market scenario from a mean value of 1.12 to 1.18, while it remains very similar (at 1.14 with and without the capacity...
market) in the Netherlands.

- Average electricity prices both in Germany and the Netherlands slightly increase in the reference case (experiment 3), when the capacity market is introduced. In experiment 4, with RES, the average electricity prices considerably decrease both for Germany and for the Netherlands.
- For the reference case, LOLE in Germany decreases from 3.75 hours to 1.38 hours, LOLE in the Netherlands remains 7.95 hours in both scenarios. In the RES case, LOLE in Germany decreases sharply from 12.18 hours to 0.64 hours and in the Netherlands, it decreases slightly from 15 hours to 13 hours.
- In experiment 4, consumer expenditure for Germany increases by 6.7% when a capacity market is introduced, and it decreases by 5.4% for the Netherlands in the capacity market scenario.

**Interpretation**

- The increased intermittency from the RES experiments cause much greater probabilities of outages. RES, nevertheless, contributes to a much lesser average electricity price.
- Due to Germany being a consistently low price region compared to the Netherlands, there is constant export of energy from the Netherlands to Germany. This increase in demand for Germany causes more probability of shortages in the capacity market (30%) than in an isolated single country scenario, which has a probability of 23% shortage in the capacity market. The higher expenditure of consumers therefore can be attributed to the overall increase in capacity prices in Germany.

**Conclusion**

In an interconnected electricity market, the country hosting the capacity market might suffer adverse effects due to the interconnection, especially in terms of higher electricity prices due to increased demand from across the border. The presence of intermittent generation capacity seems to exacerbate this effect.

6 Conclusion

This work examines two hypothesis related to the effectiveness of implementing the capacity market in a Western European context, where the National Renewable Energy Action Plans are expected to be realized over the forthcoming decades. The first hypothesis tests the effectiveness of the capacity market in a single, isolated country in Europe, while the second hypothesis analyzes the same while considering an interconnection.

The results show that on both accounts, a capacity market, when designed well, ensures generation adequacy in a western European country. In fact, the intermittency induced by a huge proportion of renewable energy in the system, makes the capacity market an even greater necessity. This is not to say that the capacity market is the best instrument to accomplish the same goal, but it is a highly effective market-based approach for inducing the right type and the right amount of investment in generation capacity, when designed appropriately.

As for cross country effects, the capacity market ensures the desired reserve margin in the country where it has been implemented. However it does so at a higher cost to the consumers of that country. Interestingly, the model suggests that, without export constraints, between the two countries involved, the surplus capacity in the country with the capacity market dampens investment, in other words, exacerbates investment cycles, in the neighbouring country with an energy only market.

**References**


