



# **Simulating electricity market bidding and price caps in the European power markets**

## **S18 Report**



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# 1. ABBREVIATIONS

Abbreviation	Definition
CAPEX	Capital expenditures
CO <sub>2</sub>	Carbon dioxide
DE	Germany
EPEX	European Power Exchange
FOC	Fixed operating costs
FR	France
MCP	Market clearing price
OPEX	Operating expenditures
OTC	Over-the-counter
Strategy A	Marginal Cost Bidding
Strategy B	Next Cluster Bidding
Strategy C	Oligopoly Bidding
Strategy D	Fixed Costs Bidding

## 2. INTRODUCTION AND OBJECTIVE OF THE STUDY

The present document has been prepared by the Institute of Power Systems and Power Economics (IAEW) at RWTH Aachen University in response to the Terms of Reference included under ENER/C2/2014-639<sup>1</sup>. Readers should note that the report presents the views of the Consultant, which do not necessarily coincide with those of the Commission.

In the context of evaluating the impact of market designs on revenues of producers and the risks they face, many studies consider a so-called “marginal cost bidding” behavior for the producers. This type of bidding behavior assumes that the power producers bids on the market according to its production cost, including all costs that are production-dependent: mainly fuel costs, CO<sub>2</sub> costs, and start-up costs. This approach has several advantages, including its simplicity and the limited necessity of input data and assumptions for the market participants’ bidding strategies.

However, marginal cost bidding does not necessarily reflect the way electricity producers bid in the market in reality. In practice, during scarcity hours for instance, prices tend to go higher than the production costs of any production unit, simply because these instants are the only ones at which peaking plants can recover their fixed costs. These scarcity situations are few and uncertain, though. As the modeling of bidding strategies may have an impact on the estimated risk profiles of power producers, it is important to simulate and analyze them within the context of existing electricity markets which presents the goal of this study.

Thus, this study demonstrates how METIS can be applied to simulate different bidding strategies on the day-ahead market<sup>2</sup>. Therefore, we implement a new module in METIS, which enables a more sophisticated evaluation of bidding behavior in electricity markets. By doing so, the scope of investigations not only covers the well-known marginal cost bidding but also further strategies (e.g., oligopolistic bidding). Thereby, this study compares the estimated power producers’ revenues using different forms of market behavior. Finally, we assess the effect of price caps on marginal pricing as well as their impact on three different bidding strategies.

### 2.1. MODELING SETUP

SETUP	
Modules Used	Power system + power market
METIS version used	METIS 1.2.1
Scenario used	EUCO27 2030
Power asset modeling	Cluster level, country granularity
Time granularity	Hourly
Uncertainty modeling	50 years of weather data
Bidding strategies	Different strategies studied

<sup>1</sup> [http://ec.europa.eu/dgs/energy/tenders/doc/2014/2014s\\_152\\_272370\\_specifications.pdf](http://ec.europa.eu/dgs/energy/tenders/doc/2014/2014s_152_272370_specifications.pdf)

<sup>2</sup> The principles will be the same to model bidding strategies in other markets within METIS. At the point of this study though, only the day-ahead market model was available.

## 3. ANALYSIS OF POWER MARKETS

### 3.1. EUROPEAN POWER MARKETS

In general, the commodity electrical energy is by its nature difficult to store in large scale and in an economically feasible way. Hence, supply and demand for electrical energy have to be matched at all times. This challenge of matching production and consumption of electricity by maximizing social economic welfare constitutes the main function of power markets. Given those objectives, the (liberalized) European power markets provide a regulated, non-discriminatory, and transparent environment that is accessible for every market participant. On these markets, electricity can be traded either at power exchanges offering standardized products or through bilateral over-the-counter (OTC) trades between counterparties. [1] [2] [3]

With regard to power exchanges, market participants have different central market places for different timeframes at hand. E.g., markets for future contracts and options (long-term derivatives markets) provide a platform for traders to (financially) hedge against the volatility of wholesale prices up to six years in advance, reducing price and quantity risks<sup>3</sup>. On the other hand, short-term spot markets allow traders to optimize their generation portfolio for the next (day-ahead) or the same day (intraday).

Day-ahead trading is mainly based on hourly contracts (24 hour intervals) for the following day, seven days a week. At the EPEX Spot day-ahead auction, the price floor is at -500 €/MWh and the price cap at 3,000 €/MWh. Gate closure time is 12 pm. From the bids, aggregated supply and demand curves are formed after trading; the intersection of both curves determines the market clearing price (MCP). This MCP is then applied to all executed orders (uniform pricing method). Executed orders are sales offers that are strictly below the MCP and purchase bids that are strictly above the MCP. Day-ahead trading allows market participants to optimize their electricity portfolio for the next day (make-or-buy-decision). Thereby, the upcoming multi-regional coupling of the day-ahead market results in an increased liquidity and converging prices between the respective market areas. [1]

Intraday trading, on the other hand, is intended to compensate for fluctuating consumption and volatile production when getting closer to the physical delivery time [1]. Besides the uniform pricing auction, analogous to the day-ahead trading, intraday trading also allows transactions carried out in the form of continuous trading. For this, sales and purchase bids are entered anonymously in an open order book. Two transactions are brought together and executed when the price of the highest purchase order is greater than or equal to the price of the lowest sales order [1]. At the EPEX Spot intraday (continuous), the price range of the bids comprises -9,999 € to 9,999 €. The coupling of the different intraday markets in Europe is not as common as for the day-ahead markets but is part of the plan to create a European internal market without access restrictions. [1]

Because of the great significance of the day-ahead market for the allocation of existing resources and the dispatch of power stations, the following analysis focuses on the day-ahead market.

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<sup>3</sup> Since the fulfillment at the long-term derivative market is usually financial, further analyses focus on short-term spot markets involving physical fulfillment.

### 3.2. DAY-AHEAD AUCTION WITH PERFECT COMPETITION

To explain the phenomena of bidding behavior, we introduce the economic model of a perfect competition first. The key aspect of a perfect competition is that no market participant is able to affect the market price. This is due to the assumption, that there is an infinite amount of buyers and sellers participating in the market for electricity. Therefore, all participants are seen as price takers. Sellers offer their product to a price equal to their marginal costs (fuel costs, costs for emission allowances, and start-up costs), while buyers offer to buy these products to a price equal to the marginal value they have placed on the product. The MCP is then set by the intersection of the supply and demand curves and cannot be affected by buyers, nor sellers. Bidding any price higher than marginal costs would eliminate profitable sales without any corresponding gain from the higher price. In conclusion, energy is supplied by the least-cost units at all times. This results in the most efficient distribution of energy, encouraging the use of this bidding behavior as a benchmark for market performance. In general, the performance of a market can be assessed by a term called social welfare defined by the sum of consumer surplus and producer surplus. It describes the combination of the cost for a commodity (here: energy) and the resulting benefit for the society. Consequently, perfect competition always results in a maximum social welfare. [5]

When applying this theoretical model of perfect competition to the day-ahead market, the principle of uniform price formation becomes evident. The price formed on the day-ahead market, thus, results from the marginal costs of the utilized power plant with the highest marginal costs. Figure 1 schematically shows this so-called merit order of marginal costs **Error! Reference source not found.**. As depicted, the market participants' bids, or marginal costs respectively, are arranged in an ascending order. The last unit of generation needed to serve the demand of electric energy sets the clearing price. Therefore, generation units paid above their bids can recover a part of their fixed costs. Hence, there is no incentive to issue a bid above marginal costs, as the probability of the bid being executed is significantly reduced when considering an infinite number of sellers. Although a bid below marginal costs increases the probability of the bid being executed, the respective situations carry the danger of resulting in a loss for the plant. [2] [6] [7]

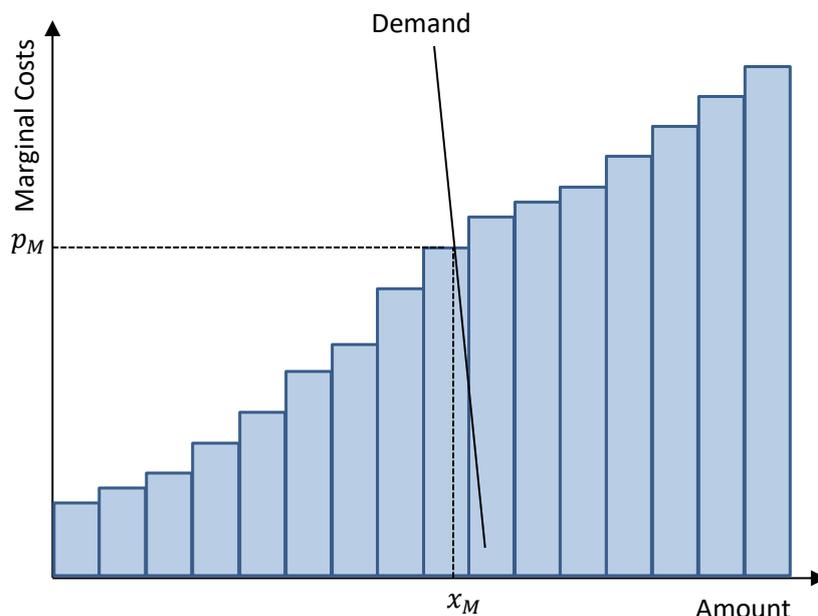


Figure 1 : Merit-Order in an electricity market with perfect competition

### 3.3. BIDDING BEHAVIOR

As mentioned above, in a perfect competition no power supplier would be able to affect the market price by bidding prices other than its marginal costs. This circumstance makes the supplier a price-taker. In reality, there is, however, a limited number of market participants with different technologies, each with a different cost structure. Furthermore, a vendor can be the owner of several power plants. Thereby, bidding for an entire portfolio of plants and technologies offers a wider scope of action, than offering prices for energy of a single plant. Incorporating those market conditions and structures, with motivation to exploit imperfections and inefficiencies in the market, is a form of strategic bidding. A successful use of this technique to increase a suppliers' profit without lowering its production costs demonstrates the operator's market power. In other words, market power is the ability of a supplier to influence and, at the same time, benefit from market prices. Although, reaching the optimum (a market offering no possibility of exploiting market power) should be the goal, modern electricity markets show these imperfections and, therefore, enable the use of strategic bidding and exercising market power. [8]

As a remark we must say, that, as stated in different (national) regulations (e.g., §29 GWB), it is forbidden to exploit market power situations in the electricity markets.

### 3.4. DAY-AHEAD AUCTION WITH AN OLIGOPOLISTIC STRUCTURE

In an imperfect electricity market, not all actors act as a price-taker and accordingly, market power can be exercised. Thereby, different strategies are possible for market-makers. A bid can be placed above marginal costs, capacity can be withheld or plants can be decommissioned [9]. A bid above marginal costs is useful for market-oriented providers if this increases the MCP and, despite a possible reduction in volume. Additional revenues compensate this loss. Figure 2 illustrates how retention of capacity, as an example of bidding behavior, can also be useful for a market-oriented supplier, even if all market participants bid at their marginal costs.

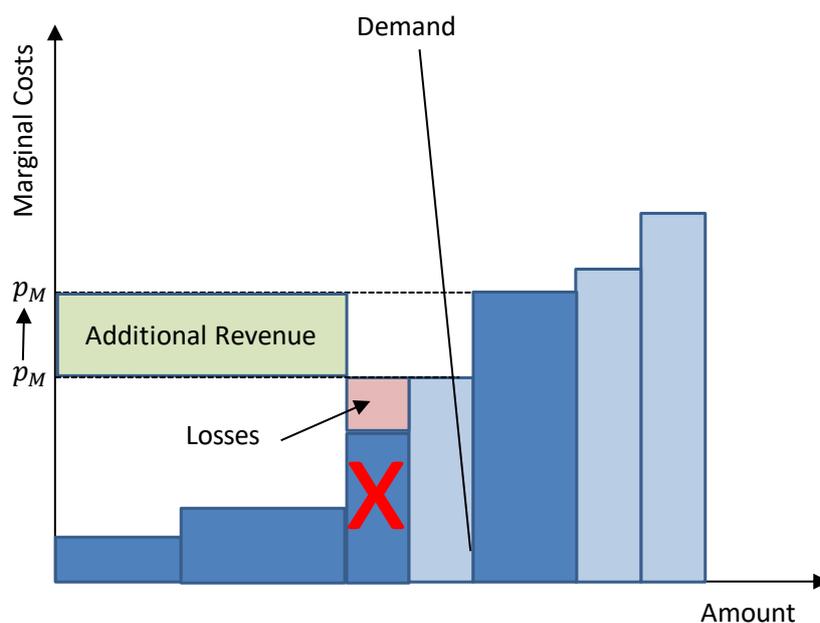


Figure 2 : Impact of capacity retention

As shown in Figure 2, an operator takes a power plant out of the market losing its generated generation surplus, if the power plant is not prevailing. Due to the retention of

capacity, there is less supply and, consequently, the MCP increases. The remaining power plants operated by the same supplier, thus, generate a higher generation surplus. It is, therefore, a sensible strategic restraint, if the additional revenues exceed the loss from the retention. Similar considerations can also be drawn for plant decommissioning leading to a permanent drop in supply. Supposing the reality-based assumption that there are both small price takers and large suppliers with the possibility of influencing prices in the market, the optimal bidding strategies for these groups differ [10]. As above-mentioned, in research dealing with the simulation of electricity markets, suppliers are usually modeled as price takers bidding at their marginal costs [11]. As in the case of complete competition, these suppliers have no influence on the MCP and, therefore, also no incentive to bid above their marginal costs. On the other hand, providers with the possibility to influence prices are faced with a more complex bidding decision since they have the possibility to include strategic aspects such as surcharges on marginal costs or capacity retention in the bidding process. In addition, an interdependent decision-making situation arises between the market players. The problem can be mapped by decision-theoretic optimization models, play-theoretic equilibrium models or even agent-based simulations. Thus, a power plant can maximize its hourly profit in an optimization problem. This requires the expected demand and the expected bidding behavior of its competitors [12]. Also, oligopolistic models (Bertrand models, Cournot Nash models, supply balance models and Nash models with a non-continuous solution space) can be used to represent the market [9]. In addition, learning algorithms are used in agent-based simulations, which allow the power plants to determine the optimal bidding strategy based on their profits from price mark-ups in past auctions.

## 4. MODELING OF BIDDING STRATEGIES

In the following, we introduce and explain four different bidding strategies. It is assumed that none of the strategies changes the prevailing merit order of the bids in the market<sup>4</sup>. Thus, every operator pursues the same bidding behavior and, thus, same bidding strategy. I.e. every energy producer only increases the amount of the bid up to the point after which the subsequent operator in the merit order, following the same strategy, would beat the offer. Section 8.1 (annex) gives a more detailed explanation of the implementation in METIS.

In exemplary investigations, all four bidding strategies are applied and the impact on prices and revenues is analyzed (cf. Section 5).

For reasons of simplicity, the mathematical formulations of the following bidding strategies are not included in Section 4. However, a detailed formulation is given in Section 8.1 (annex).

### 4.1. MARGINAL COST BIDDING

Marginal Cost Bidding describes the case when each operator bids according to its actual variable production costs of the technology used. By doing so, none of the market participants include any kind of mark-up in their bids. This behavior reflects the model of the energy only market with perfect competition (cf. Section 3.2.). As stated above, this strategy also serves the function as a reference for the bidding strategies introduced in the following.

### 4.2. NEXT CLUSTER BIDDING

Instead of limiting the amount of the bid to the marginal costs of the respective power plant (here: technology cluster), bidding behavior incorporates certain mark-ups depending on the strategy. Next Cluster Bidding strategy comprises a mark-up on the marginal costs of production depending on the utilization of each cluster's (available) capacity. Based on the assumption, that operators anticipate their position in the merit order, the expected demand, and, hence, the expected utilization of a technology cluster, the mark-up increases stepwise with a growing utilization (cf. Figure 3). However, it is assumed that the overall bid price never exceeds the marginal costs of the next technology cluster in the merit order [5]. As depicted in Figure 3, the operators of hard coal assets increase their mark-up with a growing utilization of their technology cluster. Yet, the marginal costs of combined-cycle gas turbines (CCGT) put a maximum cap on the respective mark-up. The underlying step function of the mark-up can be adapted to the users' investigation scenario.

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<sup>4</sup> This formulation represents a simplified modeling of bidding behavior (to remain compatible to METIS) and neglects a game-theoretic approach.

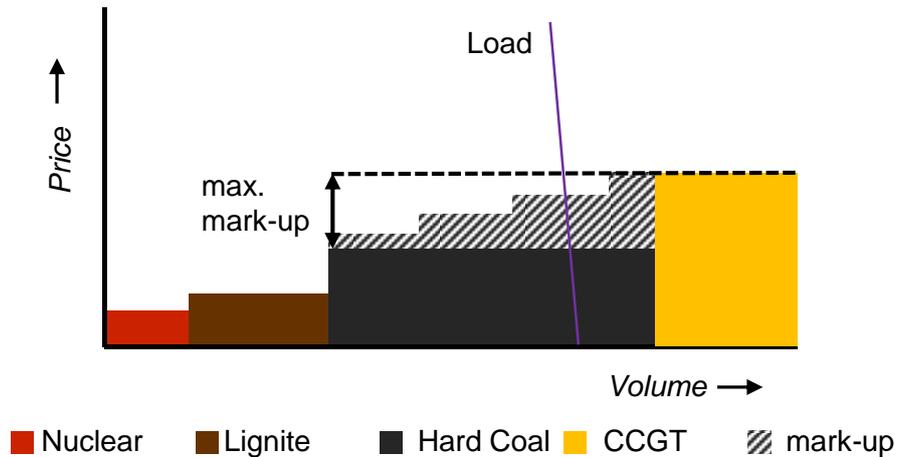


Figure 3 : Impact of Next Cluster Bidding on price bids

### 4.3. OLIGOPOLY BIDDING

In Oligopoly Bidding the operator of the power plant with the highest costs that is still needed to cover the load adds a mark-up on its marginal costs. This mark-up bases on the market share and portfolio of the respective cluster's operator.

In detail, if there is an operator in the respective technology cluster (whose assets have slightly higher marginal costs), no mark-up will be realized (cf. Figure 4 - A). Oppositely, if there is no other power plant with a different operator in the lastly contracted technology cluster a mark-up will be included into the bid price. This mark-up, then, depends on the ownership structure of the next technology cluster in the merit order. In case that assets in the next non-contracted technology cluster do not belong to the lastly contracted operator, the mark-up is limited by the marginal costs of the next cluster (cf. Figure 4 - B). However, if the entire next technology cluster does belong to the operator, the operator increases the mark-up of both clusters to reach the production costs of the subsequent cluster owned by a different operator (cf. Figure 4 - C).

In terms of Oligopoly Bidding it is assumed that the marginal costs of each asset differs and, therefore, the assets and respective operators in each technology cluster can unambiguously be ordered in the merit order. This assumption neglects an extended consideration of game theory in terms of this bidding strategy.

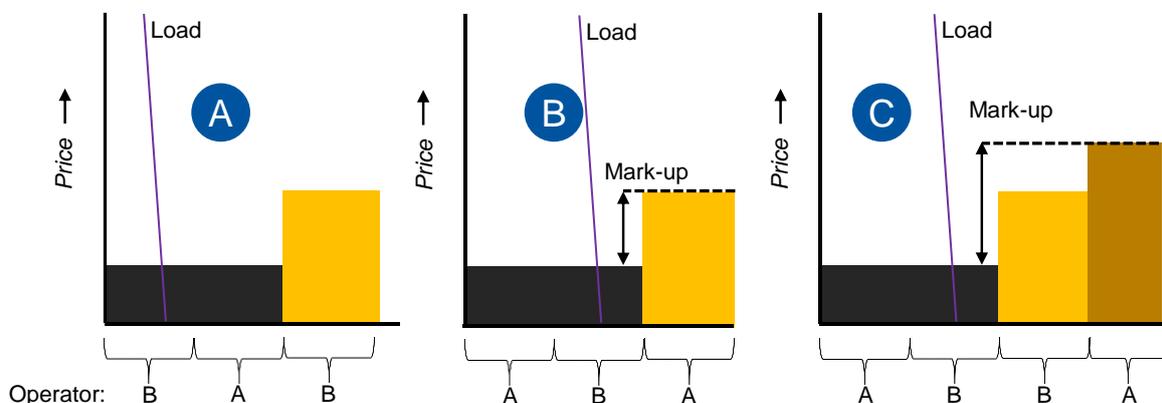


Figure 4 : Impact of Oligopoly Bidding on price bids with different market share

This modeling of Oligopoly Bidding can be interpreted as an upper bound of the bids. In markets shaped by only a few operators, regulators monitor that none of the market participants abuses his market power.

#### 4.4. FIXED COSTS BIDDING

Bidding according to fixed costs describes a strategy, in which every operator adds a mark-up motivated by fixed costs (OPEX and/or CAPEX) on the marginal costs of each technology cluster to ensure profitability. Besides the technology of the respective assets, the mark-up significantly depends on the age and yearly generation of the units in the cluster in terms of their degree of amortization. With regard to the mark-up of this strategy, the respective fixed costs are spread over the operating hours per year and added afterwards to the marginal costs. By limiting the mark-up to the next technology cluster's bid (which also comprises fixed costs), it is ensured that the merit order does not change, as is shown in Figure 5. [13]

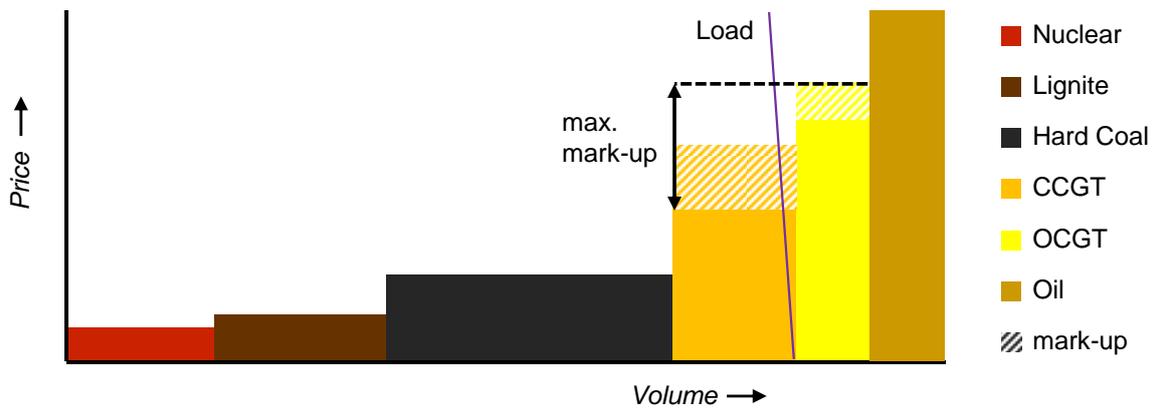


Figure 5 : Impact of Fixed Costs Bidding on price bids

## 5. EXEMPLARY INVESTIGATIONS

In the following the impact and functionality of the bidding strategies is shown by exemplary investigations. Thereby, we apply the above-modeled set of strategies (except for Oligopoly Bidding) on the European test case METIS EUCO27<sup>5</sup>. The investigations cover the impact on price duration curves, price levels as well as on generation surplus and profits of the respective assets. Furthermore, various bidding behaviours were simulated under different levels of price caps, in order to assess the impact of a price cap regulation under different contexts.

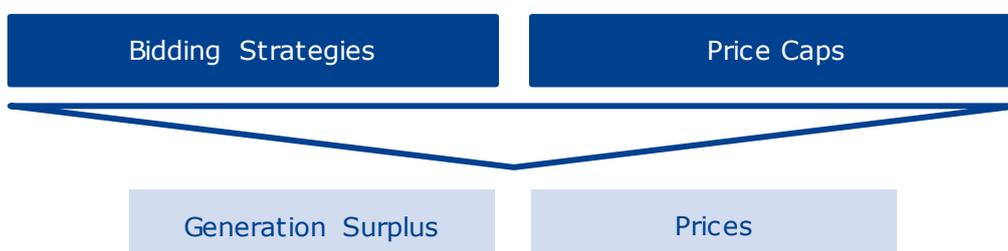
With regard to the illustration of the results, we introduce the below-listed abbreviations for the following investigations:

- Marginal Cost Bidding: Strategy A
- Next Cluster Bidding: Strategy B
- Oligopoly Bidding: Strategy C
- Fixed Costs Bidding: Strategy D

### 5.1. COST-BASED BIDDING AND NEXT CLUSTER BIDDING

The performed simulations prove that bidding behavior significantly affects wholesale prices and, hence, profits. However, the extent of this effect is strongly dependent on the considered stack, i.e., its structure (and merit order). With a growing heterogeneity of the generation system in terms of marginal costs, bidding strategies show a declining impact. When restricting bidding behavior by means of maximum price caps, those caps become binding in numerous hours of the year, in particular with regard to Fixed Costs Bidding. Those finding, amongst others, are corroborated by the following exemplary investigations.

We structure the following exemplary investigations and the respective results as follows. Firstly, the change of wholesale prices is investigated. Given those (adjusted) prices, we evaluate the impact of bidding strategies on the producers' generation surplus. In addition, price caps limiting possible mark-ups are introduced and their effect on the generation surplus is emphasized.



*Figure 6 : Investigation program – schematic overview*

All investigations on Strategy A, B, and D are carried out for the entire European power system on 50 different test cases<sup>6</sup> with different weather data. I.e., each test case includes a different (historic) meteorological year affecting the intermittent feed-in of renewables significantly. For reasons of clarity, the following evaluations only cover (but are not limited to) France and Germany. Since Strategy A (Marginal Cost Bidding) does

<sup>5</sup> METIS EUCO27 scenario has been calibrated upon PRIMES EUCO27 results for 2030.

<sup>6</sup> We enumerated the test cases in ascending order as a reference for the following investigations.

not include any kind of mark-up, results from this bidding behavior present the reference value for further comparison with other strategies (cf. Section 3.1). Further results considering Strategy C are given in Section 5.2.

With regard to Strategy B, the assumed step function (cf. Section 4.2.) comprises two levels of mark-ups: in case the utilization of a cluster is less than 50% of its available capacity the mark-up is 25% of the price spread between the respective cluster's marginal costs and the marginal costs of the subsequent cluster in the merit order. Else, the mark-up increases to 75% of this spread. By doing so, the exemplary two-level step function considers an increasing mark-up with a growing degree of utilization. The marginal costs of the following unit in the merit order sets the limit to the bid of the lastly contracted operator. With regard to Strategy D, the bidding behavior only considers fixed operating costs in the following investigations<sup>7</sup>.

### 5.1.1. PRICES

This subsection illustrates the impact of different strategies on the French price level by means of six exemplary test cases. As shown in Figure 7, Strategy B and D lead to an increase of the price level (Strategy B:  $\emptyset$  +22.4%; Strategy D:  $\emptyset$  +33.6%). In particular, Strategy D results in a significant increase of the average spot price as well as increase of the bandwidth. While Strategy D has the biggest effect in hours with the highest prices Next Cluster Bidding in Strategy B affects all hours of the year. The reason can be found in the low utilization hours of peak load technologies leading to a high mark-up from the fixed-costs spread over these hours. Depending on the respective bidding strategy and the simulated weather conditions the price level in France varies between 60 EUR/MWh and 100 EUR/MWh (cf. Figure 7).

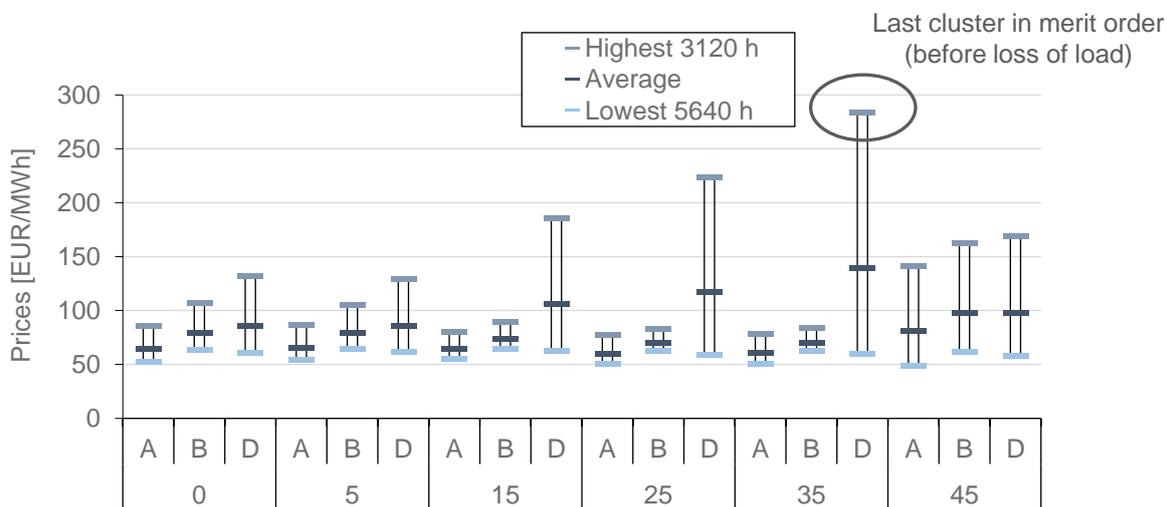


Figure 7 : Price level in France (showing exemplary test cases)

Moreover, the comparison of different test cases shows that the prices evidently are strongly affected by the meteorological conditions (weather year) influencing the intermittent feed-in of renewables, e.g., photovoltaics and wind power plants.

In order to demonstrate the effect of bidding behavior on different technologies and merit orders, Figure 8 and Figure 9 exemplarily depict price duration curves for the respective countries for a single (exemplary) test case (Test Case 0). By comparing both figures, it gets obvious that, in particular, the structure of the cluster's stack influences

<sup>7</sup> As a remark, the strategy's formulation also enables the consideration of any other type of costs.

the extent of the mark-up. Thereby, Germany has a flat merit order with numerous different generation technologies. Those small increments (in marginal costs) considerably limit the mark-up and, therefore, the effect of Strategy B and D. Only peak load power plants as the most expensive technology show potential to realize higher mark-ups (cf. Strategy D). Since the mark-ups in Strategy B substantially depend on the degree of utilization and peak load power plants only sporadically run with a small proportion (of the available capacity), the mark-ups are relatively small.

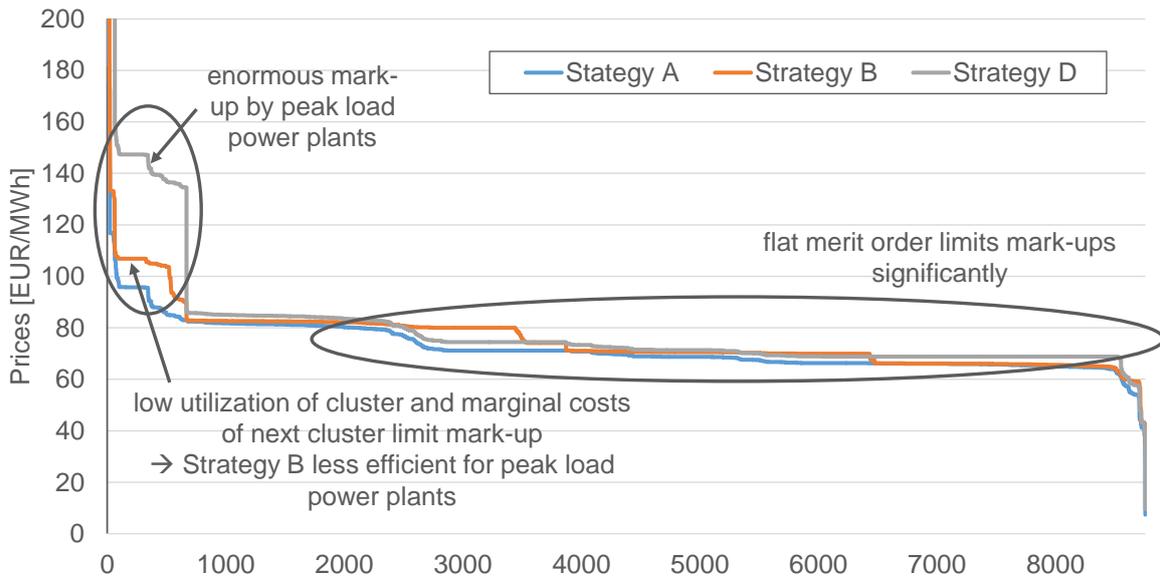


Figure 8 : Price duration curve – Germany (Test Case 0)

These effects, however, differ when analyzing the price duration curve of France. An inhomogeneous stack (comprising very low as well as very high cost technologies) provide a wide scope for mark-ups. Whereas in Germany only peak load power plants are capable of adding significant mark-ups to their bids, in France particularly nuclear power plants realize substantial mark-ups. Respective hourly mark-ups motivated by the use of Strategy D stay moderate, since the number of operating hours per year of nuclear power plants as a base load plant is large and the incorporated fixed costs are spread over numerous hours (Strategy B vice versa).

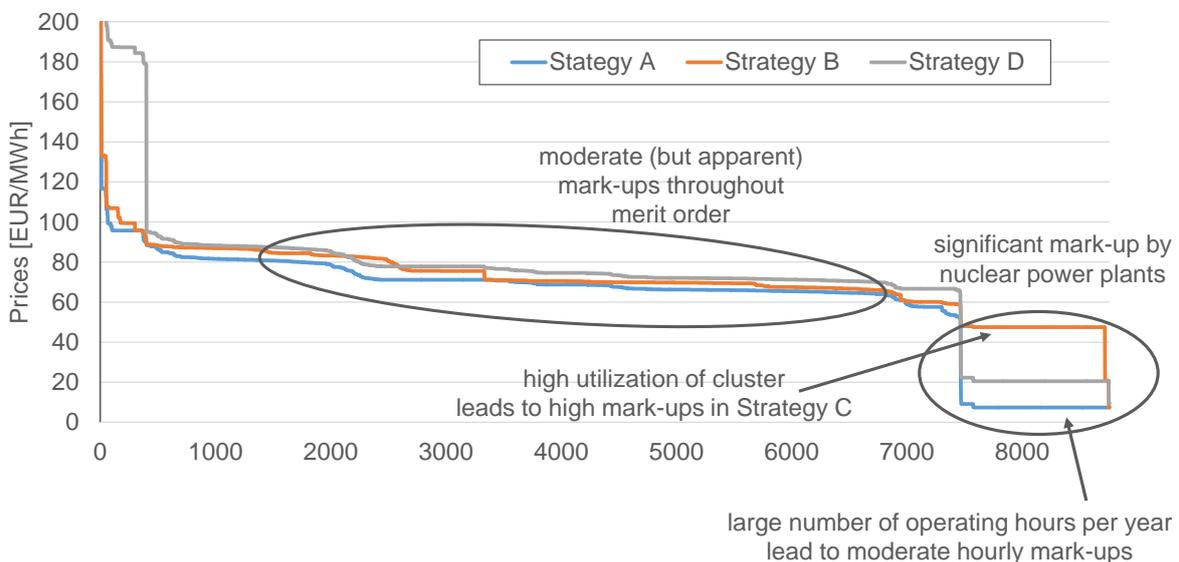


Figure 9 : Price duration curve – Germany (Test Case 0)

### 5.1.2. GENERATION SURPLUS

The above analyzed change of prices goes along with changing generation surplus (and profits), as illustrated in Figure 10. Except for nuclear energy, the generation surplus only slightly differs between the three strategies. Since Strategy D leads to the highest average price level, the same strategy also goes along with the highest generation surplus.

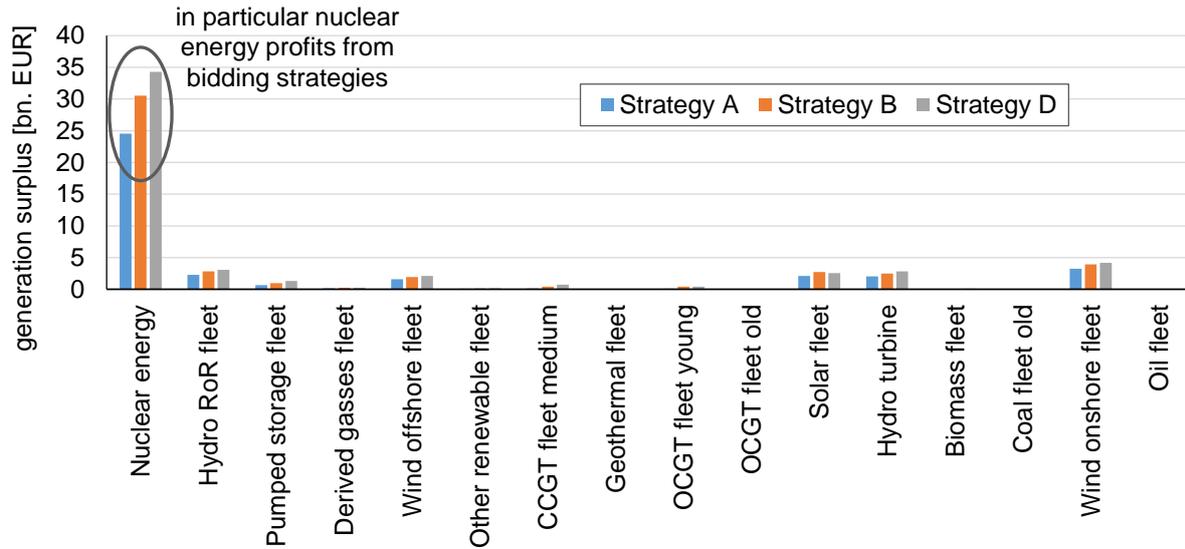


Figure 10 : Generation surplus per technology – France (Test Case 0)

In the following, we analyze the generation surplus distribution over different weather years in detail. Thus, Figure 11 illustrates the respective duration curves for nuclear energy, OCGT, and CCGT in France. Considering the shape and slope of the curves, it becomes obvious that the generation surplus strongly depends on the weather data (test case) and that applying bidding strategies only slightly changes that dependency. However, a comparison of the three strategies makes evident that Strategy D significantly affects the generation surplus of base (nuclear energy) and medium load power plants (CCGT). Particularly in case of CCGT, incorporating fixed operating costs ensures profitability in all test cases. Oppositely, the impact of Strategy D on OCGT is marginal (in contrast to Strategy B) which leads to the conclusion that profitability is not guaranteed by applying fixed costs bidding.

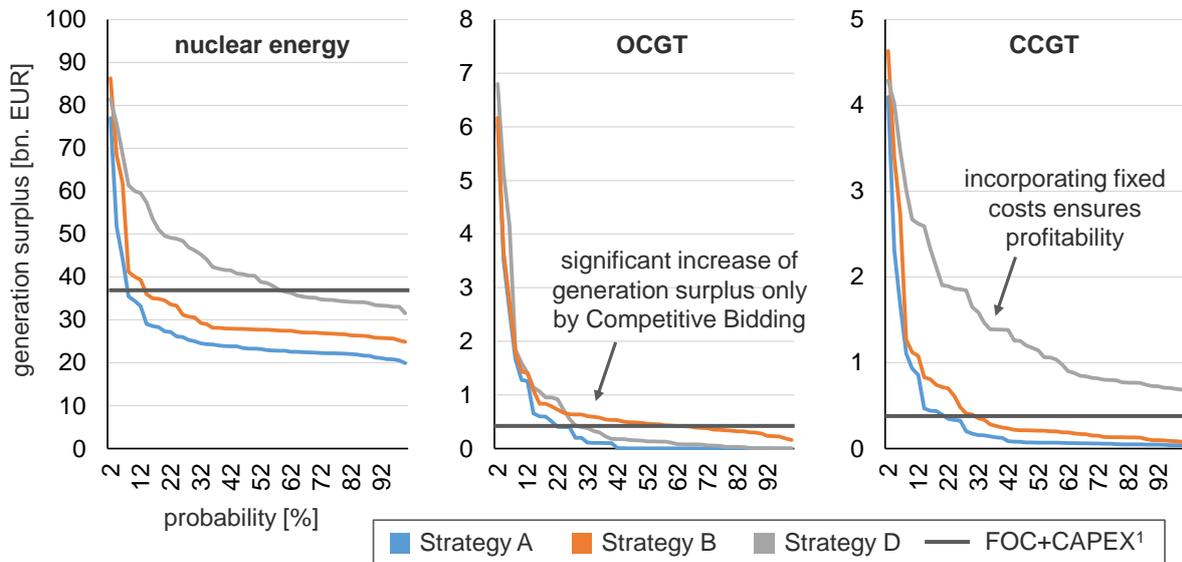


Figure 11 : Generation surplus – France (nuclear energy, OCGT, CCGT)

As stated before, Strategy D leads to the highest overall profits<sup>8</sup> in most of the test cases (cf. Figure 12). However, considering further test cases makes the dependency of the profits on the meteorological condition and, therefore, on the feed-in of renewables evident. In most cases, the revenues do not cover the fixed operating costs as well as the capital expenditures. Thus, Strategy D presents the most promising strategy to ensure profitability.

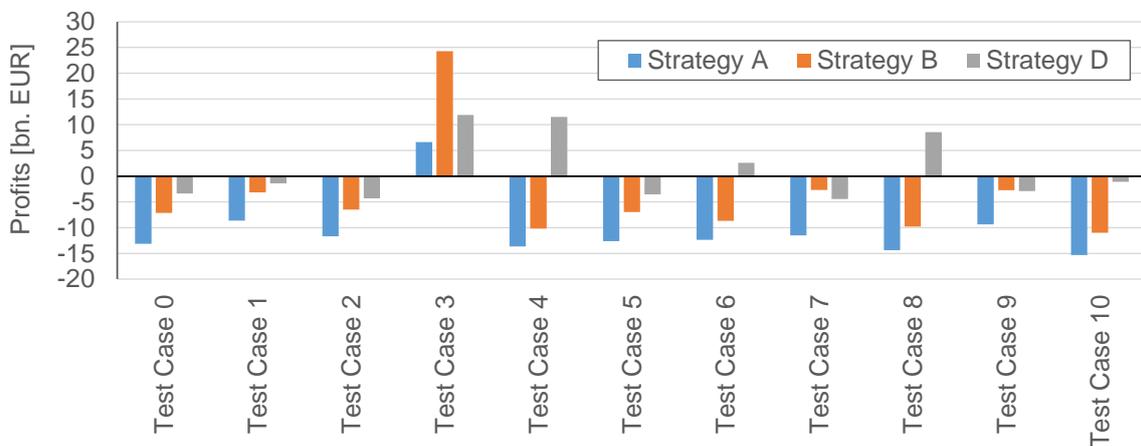


Figure 12 : Profits – France (exemplary test cases)

<sup>8</sup> Profits = generation surplus – FOC – CAPEX. Parametrization of CAPEX bases on METIS EUCO27 scenario.

This also applies to other countries, as exemplarily shown by means of Germany (cf. Figure 13). In contrast to France, the German stack does not comprise any nuclear energy (in the METIS EUCO27 scenario) which makes coal power plants (fueled by lignite and hard coal) to the technology which is most affected by the different strategies. Besides coal power plants, renewables (in particular wind energy as well as solar power) yield the highest generation surplus due to their high share regarding installed capacity. The respective profits can be found in Figure 21 (annex).

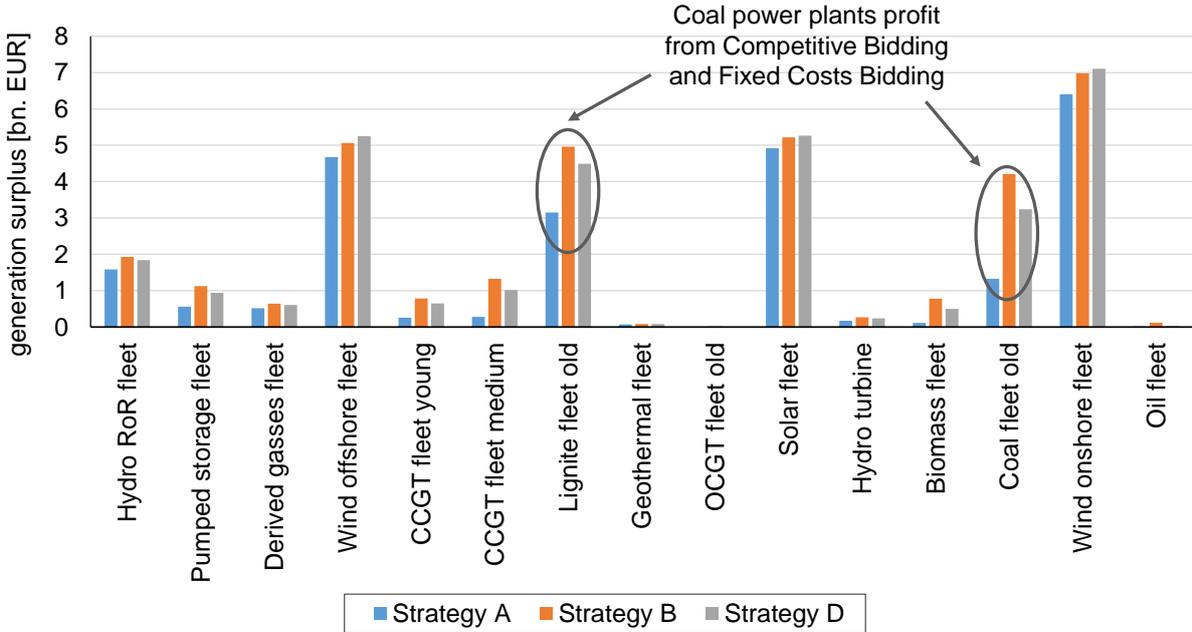


Figure 13 : Generation surplus - Germany (Test Case 0)

**5.1.3. PRICE CAPS**

In the following, different price caps are added to the simulation illustrating the interaction between bidding behavior and maximum bids. Therefore, two different price caps are defined putting a limit to the mark-ups:

1. 3,000 EUR/MWh in accordance with the maximum auction price at the day-ahead auction as well as intraday auction (EPEX Spot) [1]
2. 9,999 EUR/MWh in accordance with the maximum price at the intraday continuous (EPEX Spot) [1]

Introducing price caps to the simulations serves the function of limiting the extent of the strategy dependent mark-up. By doing so, the respective number of hours affected by peak load pricing and, hence, by caps can be identified which enables further analysis on peak units.

This number per test case (and the associated duration curve) is illustrated by Figure 14. As shown, the number of hours affected by the caps do not differ between Strategy A with a cap of 3,000 EUR/MWh (cap 3k) and the same strategy with a cap of 9,999 EUR/MWh (cap 10k). This is due to the modeling of the bidding behavior: Strategy A does not provide any kind of mark-up which means that the number of affected hours presents hours with loss of load (price: 15,000 EUR/MWh) and, hence, hours with a price higher than the predefined caps. Oppositely, Strategy B adds a mark-up to the bid. This markup depends on utilization of the technology, marginal costs of the technology as well

as the marginal costs of the next unit in the merit order (or the price of loss of load in situations of scarcity). Consequently, hours with loss of load result in an exceeding of the price caps as well as hours with scarcity. This means that hours in which the last unit of the merit order (before loss of load) is needed to cover the load, the same unit adds a mark-up which exceeds either the smaller cap of 3,000 EUR/MWh or the higher cap of 9,999 EUR/MWh depending on the utilization of the unit. Therefore, the difference between Strategy A and B can be reduced to those few hours that are characterized by scarcity.

Strategy D does not limit the mark-up in a way the other strategies do, which results in an increased number of affected hours (cf. Figure 14). In particular, the lower cap (3,000 EUR/MWh) is binding in numerous hours in most of the test cases.

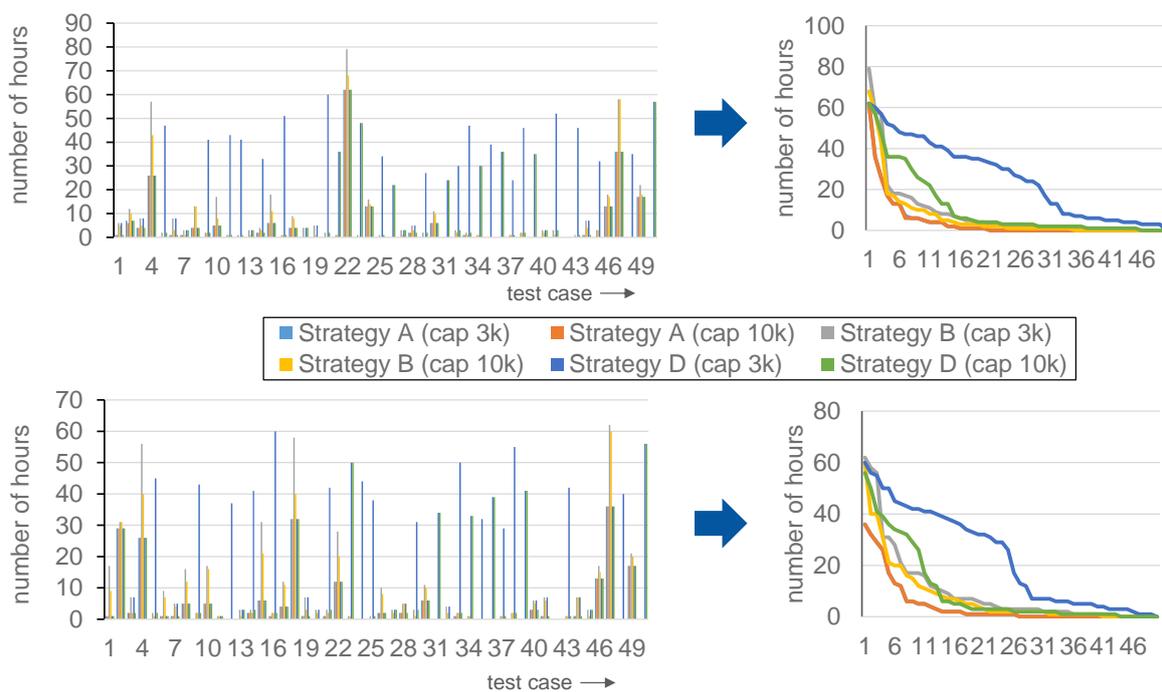


Figure 14 : Price caps – number of affected hours

With regard to the effect of price caps, Figure 15 illustrates the difference in generation surplus per year for France as a consequence of the introduction of price caps. The following conclusions can also be transferred to other countries, e.g. Germany (cf. Figure 21 in annex).

The degressive increase of the lines reveals that only in a few number of test cases the margins strongly decrease; in the rest of the cases (> 50%) only a minor difference appears. When comparing the strategies, Strategy D has the most significant impact on most of the test case resulting in a maximum decrease of 9,166 Mio. EUR (3,782 Mio. EUR) and an average decrease of 1,262 Mio. EUR (428 Mio. EUR) when considering a cap of 3,000 EUR/MWh (9,999 EUR/MWh). Oppositely, the “3k” (3,000 EUR/MWh) cap reduces the generation surplus in Strategy A by 620 Mio. EUR and in Strategy B by 865 Mio. EUR on average, whereas the “10k” (9,999 EUR/MWh) cap leads to an average decrease of 256 Mio. EUR in Strategy A and 294 Mio. EUR in Strategy B.

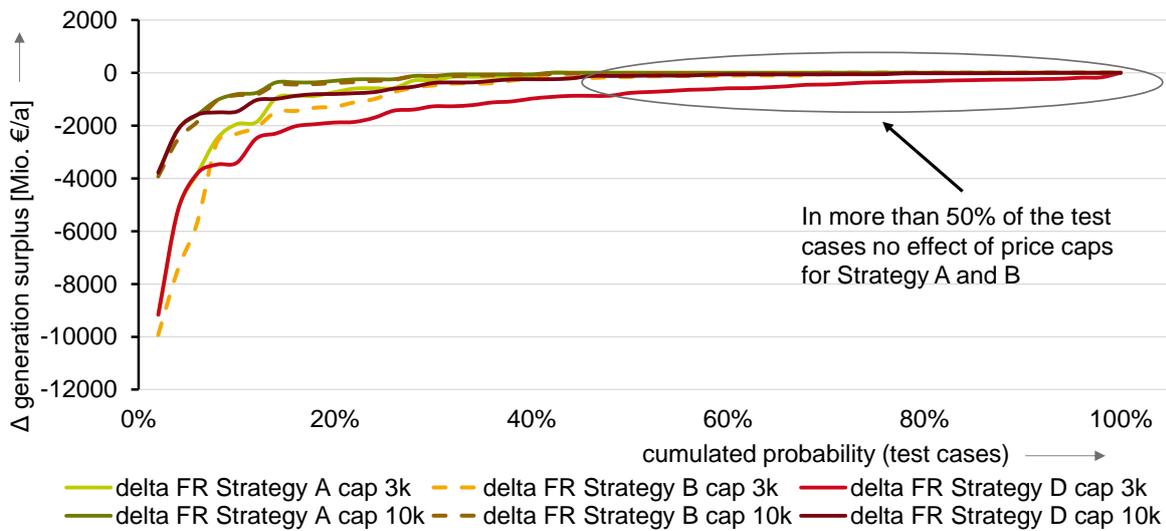


Figure 15 : Effect of price caps in France

When analyzing the effect of price caps on selected technologies, the deviation from the reference cases without caps follows a similar trend. Figure 16 exemplarily shows this trend for OCGT (young) in France. It becomes evident that OCGT as peak load power plants are highly affected by price caps, in particular when considering a cap of 3,000 EUR/MWh. Those test cases, which are characterized by a relatively high number of hours with scarcity offer peak load power plants the opportunity to incorporate tremendous mark-ups. As shown, those mark-ups constitute a huge share of the respective generation surplus by peak load pricing which is reduced by the implementation of price caps.

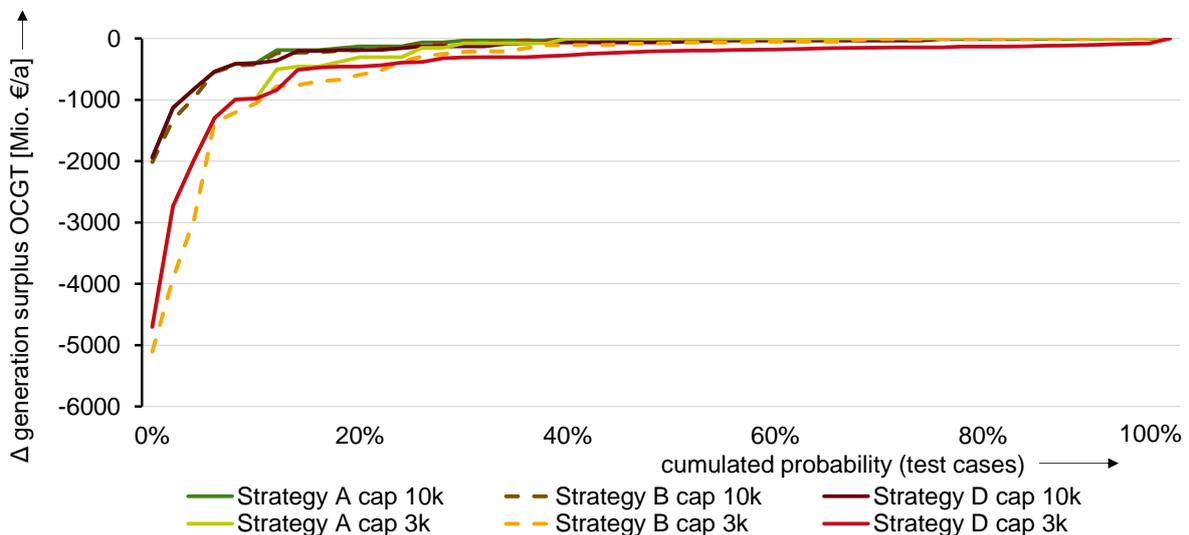


Figure 16 : Effect of price caps on OCGT (young) in France

The evaluation of price caps also emphasizes the merit of considering numerous test cases (here: 50 test cases). The results reveal that the effect of maximum caps is highly dependent on the feed-in of renewable energy sources, i.e. the meteorological conditions, which makes the application of one single (characteristic) weather year insufficient for investigations related to bidding behavior.

## 5.2. OLIGOPOLY BIDDING

As analyzed before, Oligopoly Bidding highly depends on the market share and portfolio of every market participant (operator). Since the exact ownership distribution of the European power system (as well as the distribution of the future system) is not parametrizable, Oligopoly Bidding (Strategy C) is applied on a different (simplified) scenario. I.e., all market areas are aggregated except for France and Germany on which the focus is laid for the upcoming investigation.



Figure 17 : Geographical scope of the scenario

The scenario includes two variations in terms of ownership distribution (in France and Germany). Thereby, the French stack is divided into three operators and the German stack into five operators. In Variation 1 ("V1") all lignite-fired power plants are owned by one single operator ("DE2") whereas in Variation 2 ("V2") another operator also provides a share (75 % by "DE2" and 25 % by "DE1"). In France the variation refers to nuclear energy: Variation 1 presents an ownership distribution in which all nuclear power plants belong to one single operator ("FR1") whereas in Variation 2 the assets are divided onto three operators (50 % by "FR1", 25 % by "FR2", and 25 % by "FR3").

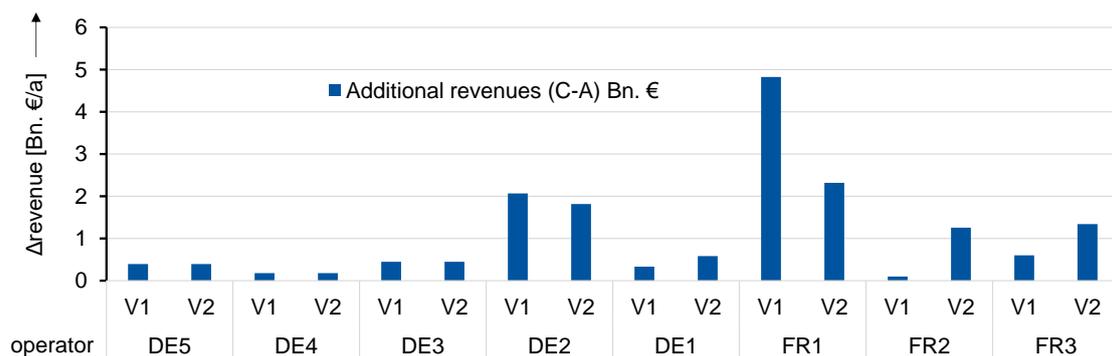
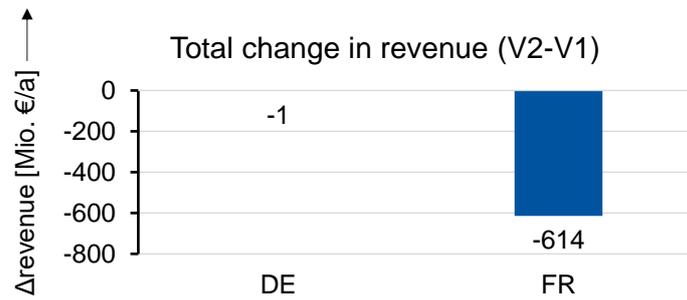


Figure 18 : Effect of ownership distribution on Oligopoly Bidding

Figure 18 depicts the effect of Strategy C by comparing revenues between Strategy A as a reference and Strategy C. It can be stated that Oligopoly Bidding always leads to higher revenues when considering a limited number of operators (Germany: 5; France: 3). However, with a growing number of market participants this impact levels off.

In a next step, the impact of market concentration is investigated by the defined variations.



*Figure 19 : Impact of market concentration*

Considering France, a cracking of the monopoly/oligopoly results in significantly reduced revenues due to the crucial role of nuclear energy in the stack. Further splitting of the ownership distribution would strengthen that effect and lower the difference between Strategy A and C. Those exemplary investigations already indicate the effect Oligopoly Bidding has on the operators' revenues.

## 6. CONCLUSIONS

In the context of evaluating the impact of market design or measures (such as price caps) on the revenues of producers, numerous studies assume a “Marginal Cost Bidding” behavior and, thus, a perfect competition. However, this behavior does not capture the way market participants bid in the market. Therefore, this study shows how METIS is capable of simulating several different bidding strategies on a single price auction (e.g., day-ahead auction) and their impact on revenues, generation surplus as well as profits. Finally, we investigate the effect of maximum price caps on strategic bidding.

Thereby, this study presents four different bidding strategies, which are implemented in the METIS framework and evaluated afterwards by means of 50 European test cases: Marginal Cost Bidding, Next Cluster Bidding, Oligopoly Bidding, and Fixed Costs Bidding. Each of those strategies represents a certain behavior of a market participant with regard to the mark-up added to the marginal cost bid.

It is shown, that all bidding strategies result in higher revenues and profits in comparison with Marginal Cost Bidding. In particular, Fixed Costs Bidding proves to lead to higher price levels and, therefore, yields the highest revenues of the compared strategies. Consequently, this strategy is also most affected by price caps when introducing maximum mark-ups. Besides, it was proven that the extent of mark-ups and, hence, the impact of each bidding strategy is highly dependent on the generation stack (size and structure) as well as the meteorological year (i.e., feed-in by renewables). Thereby, bidding strategies particularly exploit flat merit orders with a homogeneous (marginal) cost structure.

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## 8. ANNEX

### 8.1. METHODOLOGY

In a first step, a standard system module run is performed resulting in the least-cost unit dispatch (cf. Figure 20). Given this dispatch, we identify the marginal unit with its marginal costs in the merit order for any time interval of the entire year. In accordance with the respective bidding strategy, we add a mark-up to those marginal costs and modify the bids considering the subsequent part of the merit-order. Finally, revenues and profits are computed. This methodology then iterates for every test case (weather year), as shown in Figure 20.

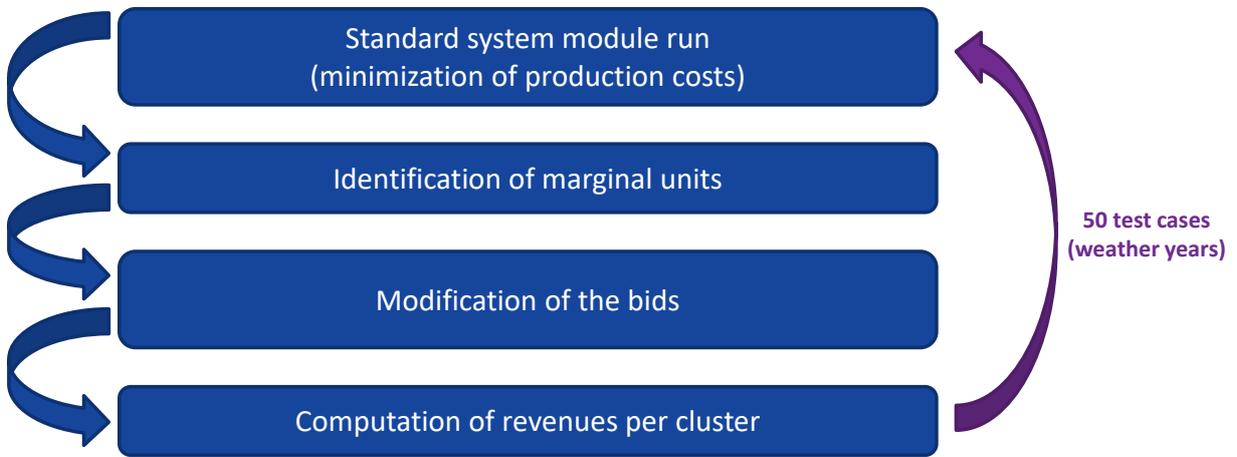


Figure 20 : Applied methodology to incorporate bidding behavior in METIS

### 8.2. MATHEMATICAL MODEL

$i$	index
$t$	time interval
$T$	set of time intervals (temporal scope)
$c$	last cluster needed to cover the load
$o$	operator
$O$	set of operators
$C_o$	cluster of operator $o$
$o_o$	last needed operator to cover the load
$R$	set of intervals with a feed-in greater zero
$x_i$	percentage surcharge after $i$ steps (input variable)
$m_{c,t}$	mark-up of cluster $c$ at time $t$
$p_{c,t}$	marginal costs of cluster $c$ at time $t$
$K_c^{FOC}$	fixed operating costs of cluster $c$
$u_{c,t}$	utilization of cluster $c$ at time $t$
$u_i$	utilization factor after $i$ steps (input variable)
$P_{c,t}$	power/feed-in of cluster $c$ at time $t$
$p_c^{install}$	installed capacity of cluster $c$

Marginal Cost Bidding

$$m_{c,t} = 0 \quad (1)$$

### Next Cluster Bidding

$$m_{c,t} = \begin{cases} x_1(p_{c+1,t} - p_{c,t}), 0 \leq u_{c,t} \leq u_1 \\ x_2(p_{c+1,t} - p_{c,t}), u_1 \leq u_{c,t} \leq u_2 \\ \dots \\ x_n(p_{c+1,t} - p_{c,t}), u_{n-1} \leq u_{c,t} \leq u_n \end{cases} \quad (2)$$

$$\text{with } u_{c,t} = \frac{P_{c,t}}{P_c^{install}} \quad (3)$$

$$x_i \in [0; 1] \forall i \in [1; n] \wedge x_1 \leq x_2 \leq \dots \leq x_n \quad (4)$$

### Oligopoly Bidding

$$m_{c,t} = p_{c_{o_1},t} - p_{c_{o_0},t} \quad (5)$$

$$p_{c_{o_1}} = \min(\{p_{c_o} \mid \exists o \in O \setminus o_o : p_{c_o} \geq p_{c_{o_0}}\}) \quad (6)$$

### Fixed Costs Bidding

$$m_{c,t} = \min(X_c, p_{c+1,t} + X_{c+1} - p_{c,t}) \quad (7)$$

$$\text{with } X_c = \begin{cases} \frac{K_c^{FOC}}{|R|}, \text{ if } |R| > 0 \\ 0, \text{ else} \end{cases} \quad (8)$$

$$R = \{P_{c,\tilde{t}} \mid \exists \tilde{t} \in T : P_{c,\tilde{t}} > 0\} \quad (9)$$

### 8.3. FURTHER RESULTS

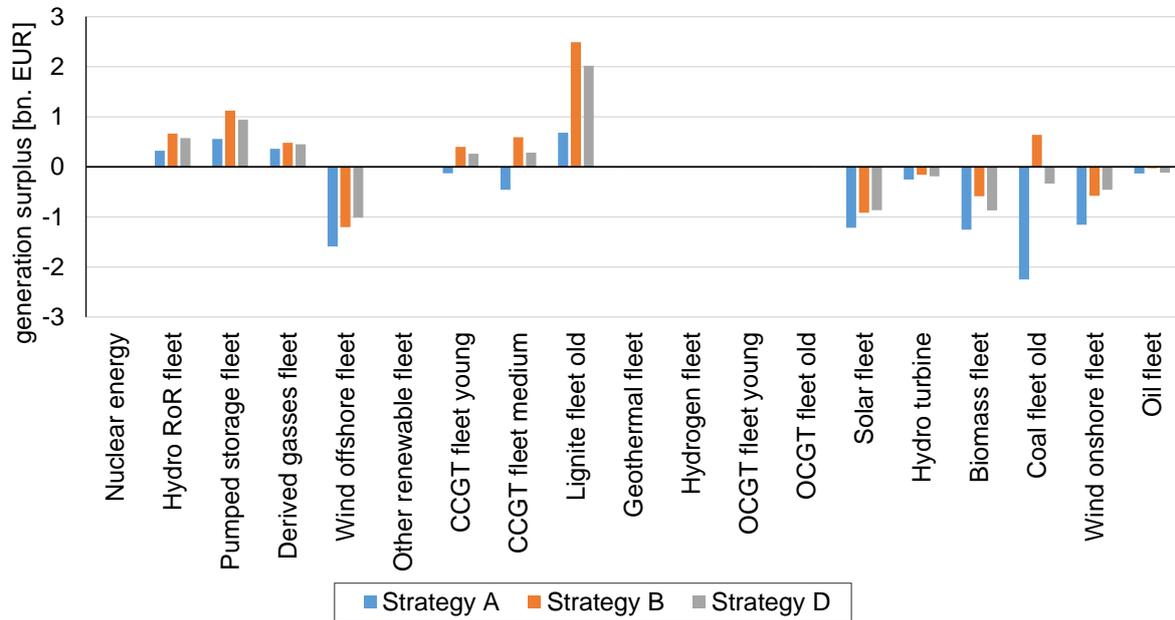


Figure 21 : Generation surplus – Germany (Test Case 0)

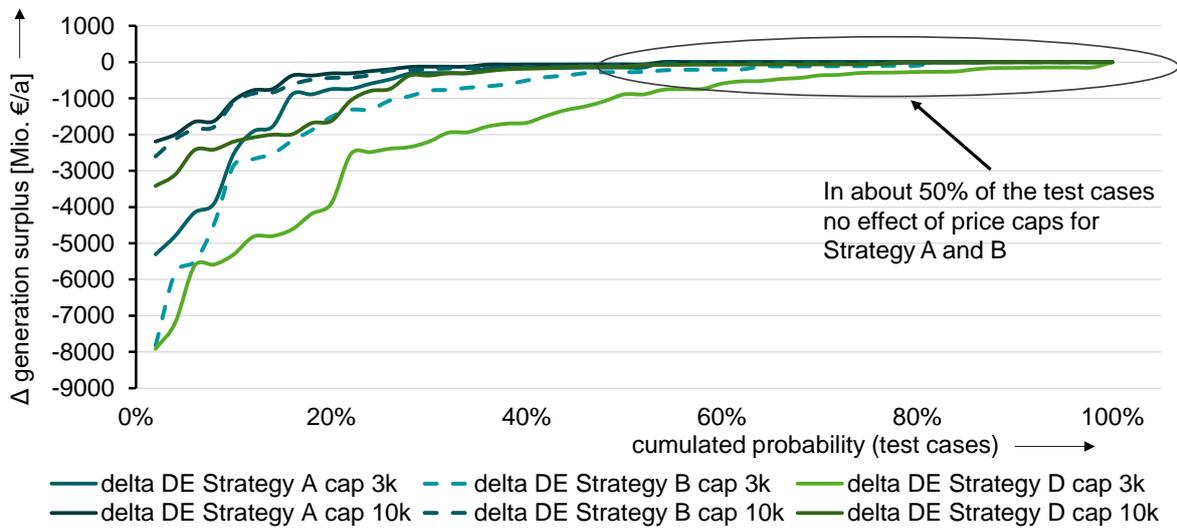


Figure 22 : Effect of price caps in Germany

