IMPLEMENTATION AND STUDY OF THE RESERVE CAPACITY MARKET IN BID AS A BASIS FOR RESEARCH OF ELECTROLYSIS PLANTS' POTENTIAL CONTRIBUTION TO THE BALANCING OF THE ELECTRICITY SYSTEM.

Master's Thesis - Civil Engineering in Energy Technology

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INTRODUCTION

Flexibility is an important factor when it comes to stabilizing and balancing the energy system, therefore the potential for electrolysis as a player in the reserve capacity market will be examined.

This project will identify the potential and incentives of electrolysis to contribute to the balancing of the electricity system. Based on existing BID3 models of a scenario based on Analysis prerequisites 2021 (AF21) projected to 2030, the reserve capacity market will be examined and implemented. Development of the model enables modelling, where potential earnings from reserve capacity payment for the plants is implemented. This will form the basis for a study of how electrolysis plants can operate flexible in the future energy system and contribute to the reserve capacity market.

BID3 has a function that holds capacity of reserves, which can be included in the optimization of scenarios for the future energy system. This function is investigated and used to implement the reserve capacity market in BID3. The base case is a scenario built on the analysis prerequisites 2021 projected to 2030. A simulation of a scenario, where electrolysis plants can supply reserve capacity and one where they do not have this option, shows that there is a significant economic incentive for participation of an electrolysis plant in the reserve capacity market.

MARKET DESIGN AND OVERVIEW

The current market design is developing, towards a more dynamic framework, where the energy and capacity market will be separate. This already exists today for mFRR, where capacity is purchased at both daily and monthly auctions, which obliges players to submit bids in the energy market. The capacity is expected to be purchased in 2030 in a common Nordic Market, where the player will place a bid with a quantity to a defined price to hold the capacity back and reserve it for potential delivery of ancillary services. If the bid is accepted the player receives a capacity payment to reserve capacity but they also obligate to submit an energy bid. The bid in the energy market is a price for delivery and activate energy, in order to the reserved capacity. In case of imbalances in the operating hour, the reserved capacity purchased in the reserve capacity market can thus be activated via the energy bids.

In 2030, Energinet is expected to purchase energy activation for aFRR in a market called, Picasso and mFRR in a market called, MARI. In this study, this division of the capacity market and the energy market is assumed and additionally also applied to FFR, FCR, FCR-D, and FCR-N as the capacity is essential for these reserves and there are often very small amounts of energy when activated. The focus of this study, however, is a study of the reserve capacity market and it is assumed that all reserves are purchased as asymmetric products, so that the up and downregulation capacity is purchased separately

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PROJECTION OF THE NEED FOR ANCILLARY SERVICES BY 2030

The quantification of the exact amount of reserve required depends on the particular state of the electricity transmission grid for a given period. This means, the final quantity can only be defined according to information of the assessment plan, meaning a projection of the need for ancillary services is encumbered with significant uncertainties and based on assumptions. The background for this assessment and projection is data extraction from a BID3 simulation based on AF21 projected to 2030. Based on data extracts from the simulation as well as the calculation and determination methods that are expected to be used in 2030 for Denmark's procurement of reserve capacity in the international markets, the need for ancillary services I 2030 used in this study will be determined, see the table.

Ancillary services	Synchronous area	Requirement [MW/hour]
mFRR capacity	DK1	684
	DK2	623
aFRR capacity	DK1	130
	DK2	90
FCR capacity	DK1	41
FCR-N capacity	DK2	29
FCR-D capacity	DK2	69
FFR capacity	DK2	100 (upregulation only)

ELECTROLYSIS PLANT AND ANCILLARY SERVICES

In agreement with the technical requirements for the delivery of ancillary services described in “Prækvalifikation af anlæg og aggregerede porteføljer” as well as the technical specifications for an Alkaline electrolysis cells (AEC), An AEC plant has the qualifications to be able to deliver ancillary services in the various reserve markets. The response time for AEC is less than 1-5 seconds if it is operating and less than 10 seconds if it is to regulate the load from hot start. In theory the fast response and ramp time enables delivery of all the different ancillary service type in accordance with Energinet's pre-qualification requirements. The only reserve type where a potential challenge may occur for AEC units to deliver the reserve is FFR in DK2. This reserve is only purchased as an upregulating product. The fast response requirements for delivery of FFR can be made possible by a potential to pull the breaks, in these situations if price incentive is present.

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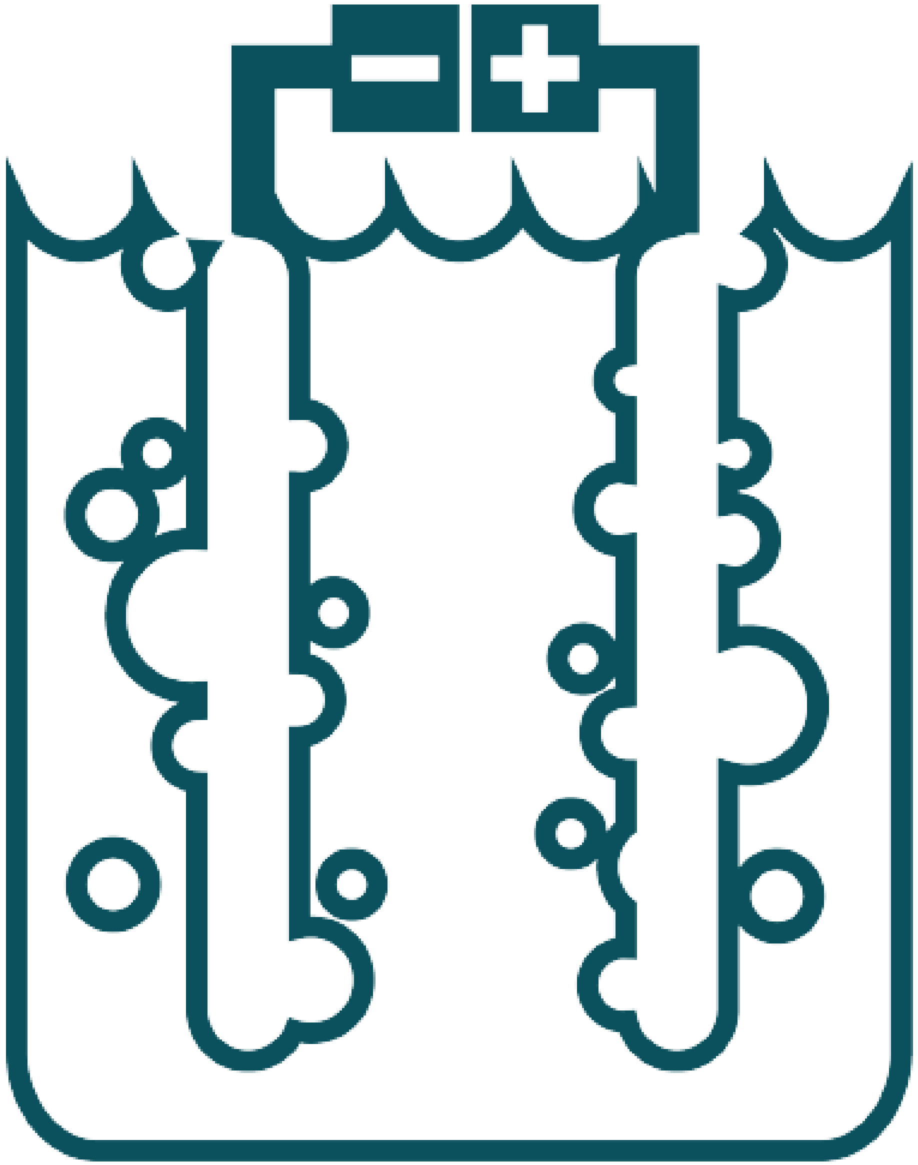


OPERATION PATTERN OF AN ELECTROLYSIS PLANT

When bidding in the various capacity markets for potential delivery of ancillary services, the majority of these markets have a GCT before the dayahead market, therefore constructive forecasts of the spot price for the coming hours is used as a basis for their bidding price.

- If the electrolysis plant is expected to be in operation (power response signal), the forecasted spot price is below the plant's threshold value i.e., the hydrogen production is economically profitable and generates profit. If the plant planning to run at full load, it can bid into the reserve capacity market with upregulation. Since the electrolysis plant is an electricity consuming plant, it can offer to make capacity available to consuming less electricity i.e., turn down the production of hydrogen.

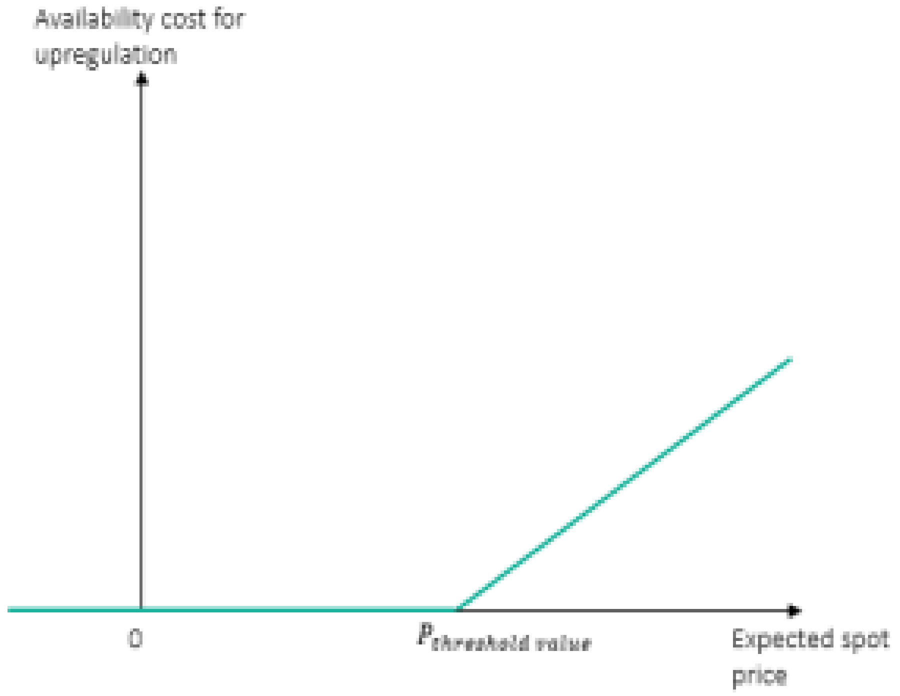
- If, the plant on the other hand, intends to run at partial load, it can bid into the reserve capacity market with both up- and downregulation i.e., reserve capacity to consume more or less electricity, by turning the production of hydrogen up or down. When bidding for downregulation in the reserve capacity market, it is a condition the plant runs at partial load or are turned off, this usually means that the spot price in the hour will be higher than the threshold value and thereby generate an economic loss for the plant to produce hydrogen.

THE RESERVE CAPACITY MARKET - UPREGULATION

The Figure shows the costs of an electrolysis plant being available with upregulating capacity for the reserve capacity marked.

If the projected spot price is lower than plant's threshold value $P_{threshold\ value}$, the plant is operating and therefore it is cost-free for the plant to be available with a given capacity for upregulation in the market, since it releases electricity by turning down the plant.

If the spot price is expected to be higher than the threshold value $P_{threshold\ value}$, the difference between the projected spot price and the threshold value will have to be included in the capacity payment. So that the plant does not suffer losses due to non-profitable hydrogen production, as the plant alternative had been turned off. This earning for the reserve capacity market can be used to reduce the cost of hydrogen production and thereby still make the economic profitable to produce hydrogen in hours where the spot price is higher than the threshold value..



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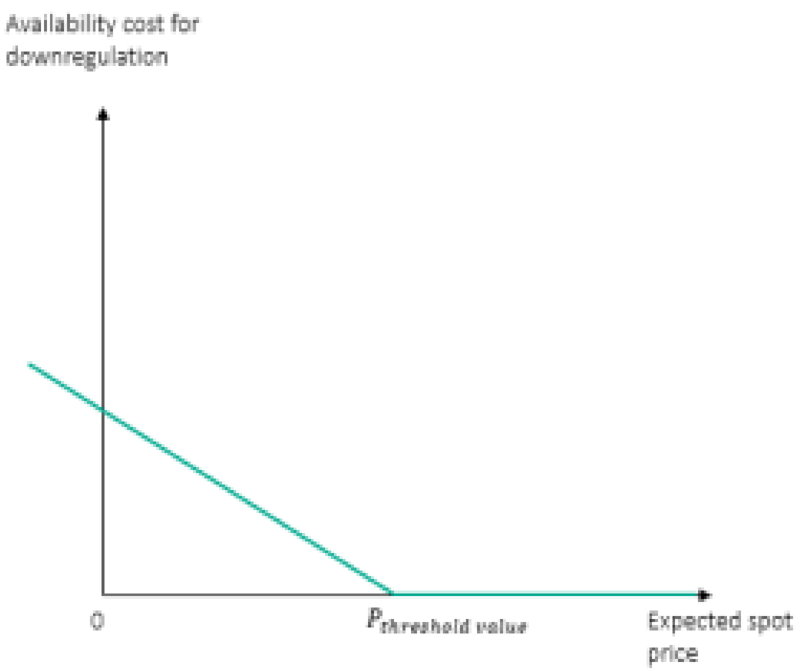
THE RESERVE CAPACITY MARKET - DOWNREGULATION

It is a condition for downregulation bids that the plant intends to operate at partial load or is non-producing. However, the plant is limited by bidding in the capacity market for hours where it does not plan to be in operation

The Figure shows the costs of an electrolysis plant being available with downregulating capacity in the reserve capacity marked. If the projected spot price is expected to be higher than the threshold value, $P_{threshold\ value}$, the plant will not be in operation, therefore it will be free to reserve the capacity for downregulation i.e., to turn up the electrolysis plant. . In the case of bids in the energy market, costs associated with starting the plant will be included.

If the projected spot price is lower than the threshold value, the electrolysis plant will expect to be in operation as hydrogen production will be profitable. Therefore, the capacity payment in this case must be equivalent associated with what is retained by profitable hydrogen production. Since the profit of producing hydrogen alternatively had been higher at a low spot price.



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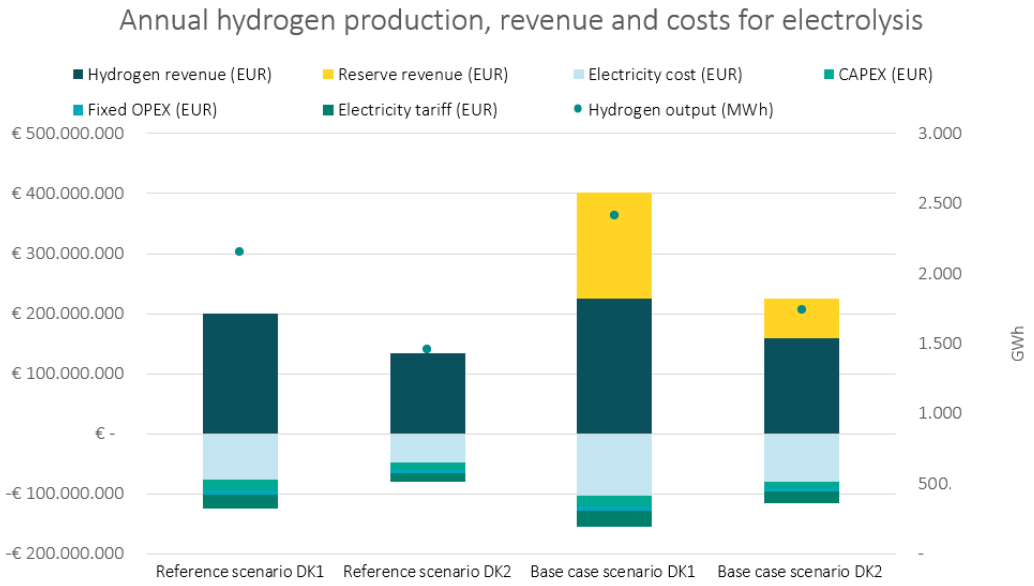
ELECTROLYSIS AS A PLAYER IN THE RESERVE CAPACITY MARKET

The impact of the supply of reserve capacity on the operation and economy of the electrolysis plant is examined. This is done by a reference scenario without reserve capacity supply from electrolysis plant as well as a base case scenario where electrolysis can contribute with 30% of their installed capacity in the reserve capacity market under the preconditions.

ELECTROLYSIS AS A PLAYER IN THE RESERVE CAPACITY MARKET

The Figure shows the hydrogen output for the installed electrolysis capacity for DK1 and DK2, in the reference- and base case scenario, as well as cost and revenue related to hydrogen production, summed up over the simulation year 2030.

It is shown how the hydrogen production is increased in the base case scenario where electrolysis contributes with reserve capacity. This is due to the capacity payment the electrolysis plant receives by participating and getting bids accepted in the reserve capacity market in principle reducing the cost of hydrogen production. In hours where the plant receives capacity payment to reserve a given amount of capacity for reserves, the income will thus correspond to the difference between the threshold value and the spot price, which will enable profitable hydrogen production in some of the hours when the spot price exceeds the threshold value. Thereby the electrolysis plant via the capacity payment will achieve additional hours of hydrogen production.



AVERAGE RESERVE CAPACITY PRICE IN 2030

The electrolysis plant is settled with the reserve capacity price of the given reserve types for the individual operating hour. The average price for the individual ancillary services for the year 2030 in this analysis is shown in the Figures. Electrolysis contributes with large capacities in the reserve capacity market. This results in a significant reduction in the average reserve capacity price in both DK1 and DK2. Considerable difference in the average reserve price for both DK1 and DK2, identify a significant impact by electrolysis plant participation in the reserve capacity market, due to their low marginal prices for supply of reserve capacity.

In both DK1 and DK2, the electrolysis plants contribute with a large amount of upregulation i.e., offering to provide capacity for turning down production and release electricity to the system. When the plant expects to be in operation and thereby consume electricity and produce hydrogen, it is in theory free of charge for the electrolysis plant to make the capacity available in the reserve capacity market.

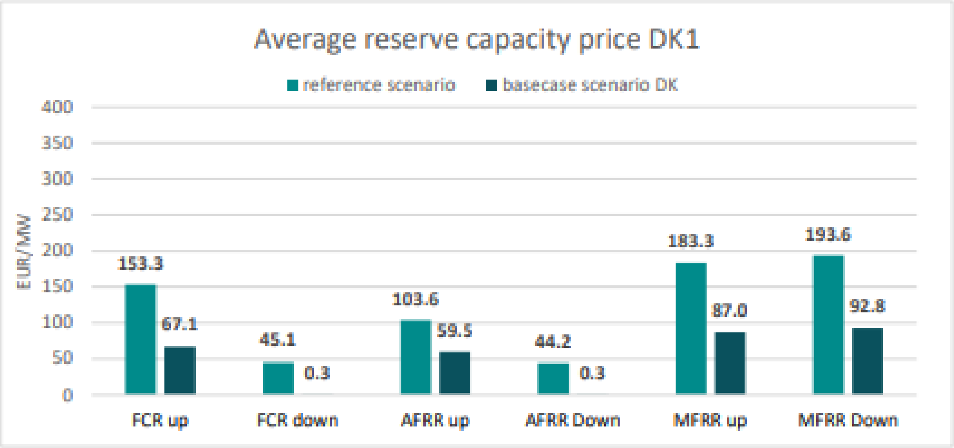
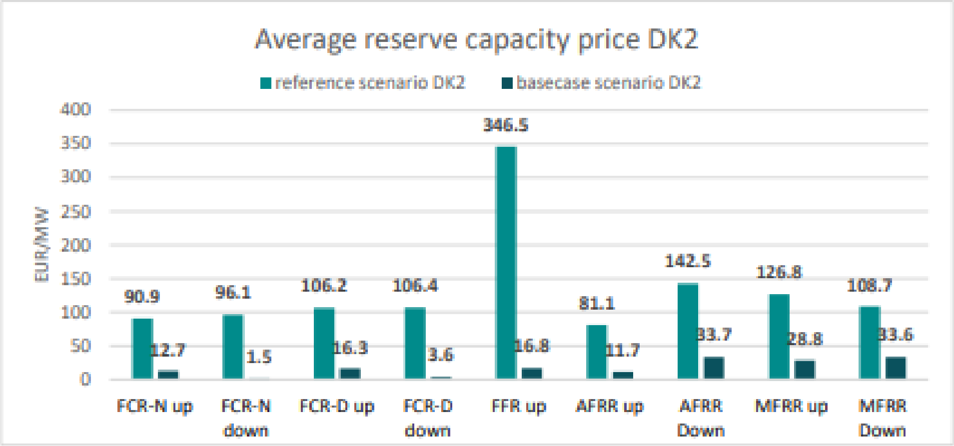
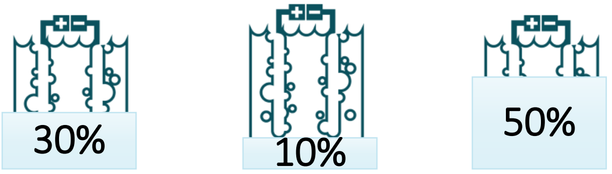


Figure 24 Average reserve capacity price in the reference scenario and the base case scenario in DK1.

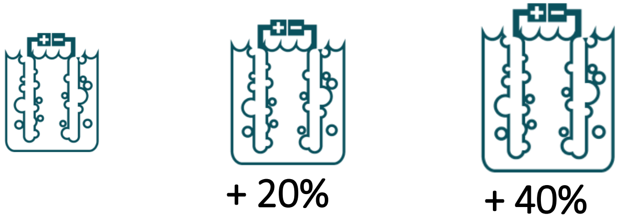


SENSITIVITY ANALYSIS

- The share of capacity electrolysis can participate with in the reserve capacity market



- The size of the installed capacity



- The plant is efficient

60% 66,5% 70% 75%

- The max price in the reserve market

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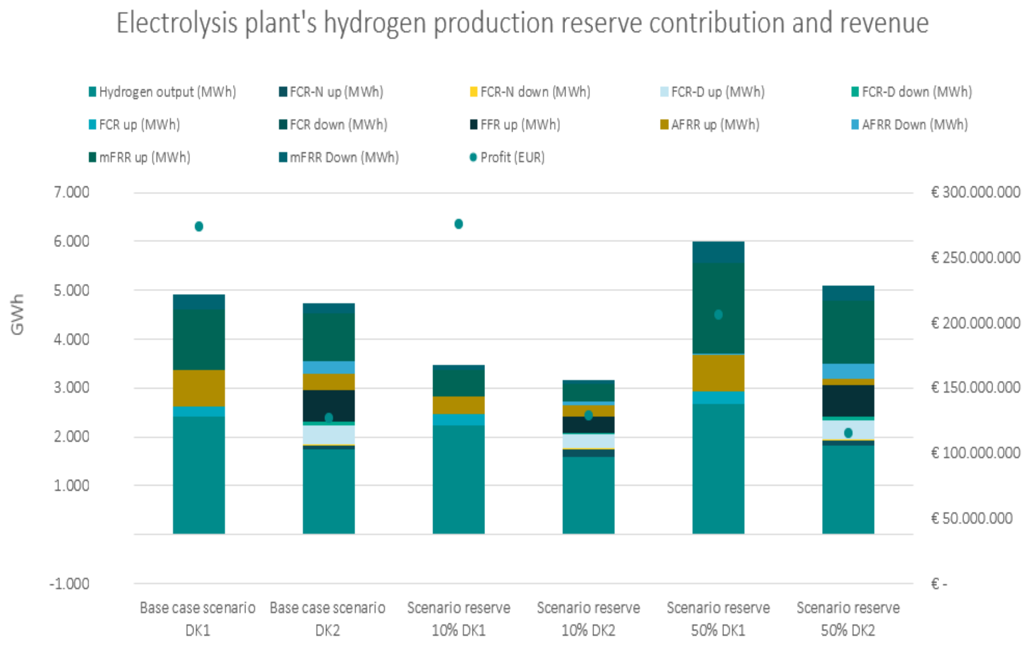
SHARE OF THE ELECTROLYSIS PLANT'S INSTALLED CAPACITY CONTRIBUTION WITHIN THE RESERVE CAPACITY MARKET

The Figure shows the total profit for hydrogen and reserves over the year 2030, as well as the hydrogen output and contribution to the supply of reserve capacity divided into the reserve types.

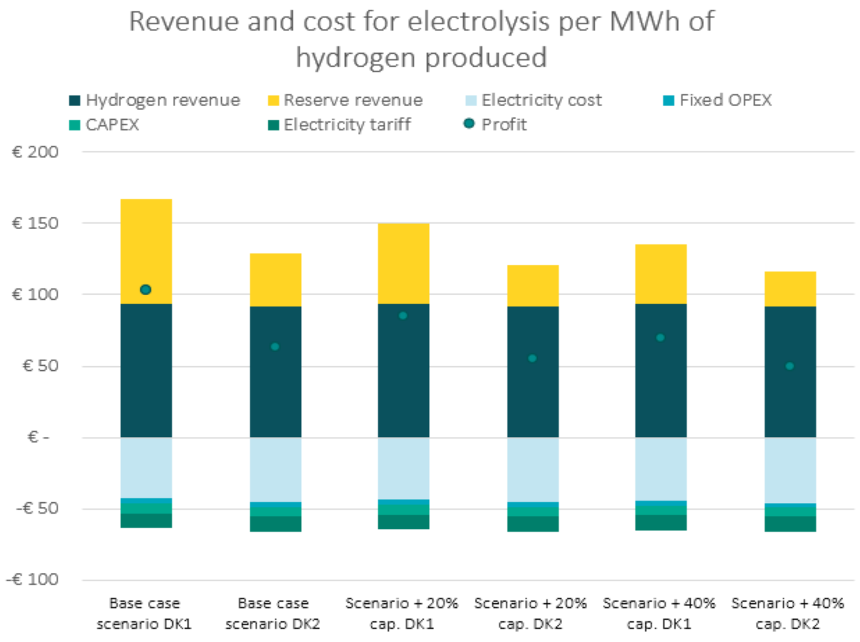


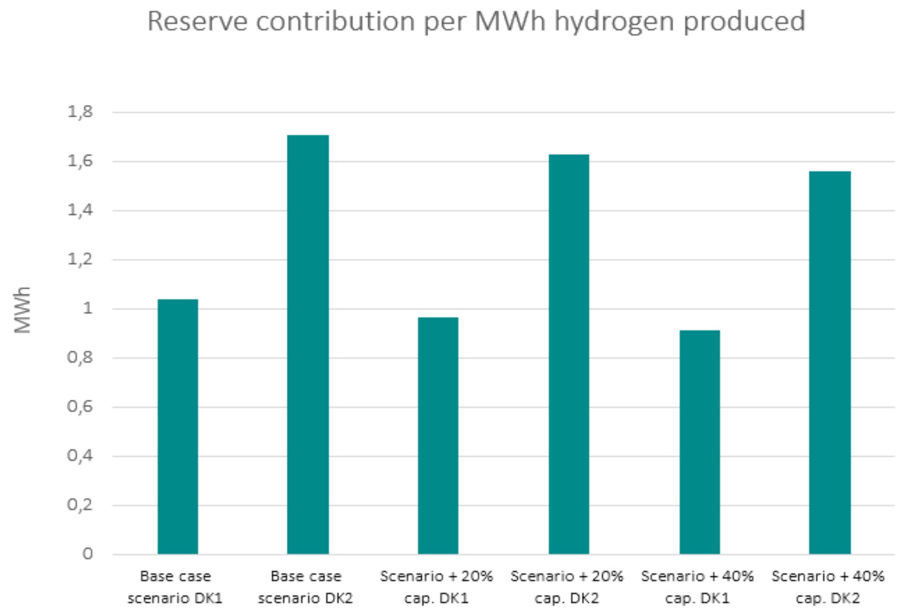
The amount of capacity electrolysis contributes with in the reserve capacity market increases depending on the proportion of capacity they can provide. The same trend applies to the hydrogen output produced it also increases marginally by increasing the share that is contributed to the reserve capacity market. The profit decreases as a result of the increased share of capacity contribution to the reserve capacity market.

There is a significant reduction in the revenue from reserve capacity payment, in the scenario where electrolysis contributes 50% of the installed capacity in the reserve capacity market. A significantly average lower reserve capacity price is seen in the scenario where electrolysis contributes 50%. Thus, the electrolysis plant is settled with a significantly lower price for the capacity delivered retained for reserves and then obtains a lower income for the produced hydrogen.

ELECTROLYSIS CAPACITY INSTALLED

The figure to the left shows the average revenue from reserves and hydrogen per MWh, as well as the costs per produced MWh of hydrogen in the scenarios. The increased capacity results in more hydrogen production, which increases the earnings for electrolysis by hydrogen sales. However, considering the profit generated per produced MWh of hydrogen, the profit decreases as an effect of the increased capacity. This is both an effect of a marginally larger CAPEX and fixed OPEX per MWh of hydrogen produced due to the larger investment in capacity and a correspondingly marginally higher cost of electricity per MWh produced. The largest factor causes by significantly lower income from reserves, which is due to the fact that a smaller reserve capacity is provided per produced MWh of hydrogen compared with the base case scenario. It appears from the left Figure that the highest profit per produced MWh of hydrogen is found in the base case scenario. The right Figure shows the amount of reserve capacity delivered per produced MWh of hydrogen, which is decreasing as an effect of the increased capacity as well as lower reserve prices, which results in reduced reserve income per produced MWh of hydrogen.

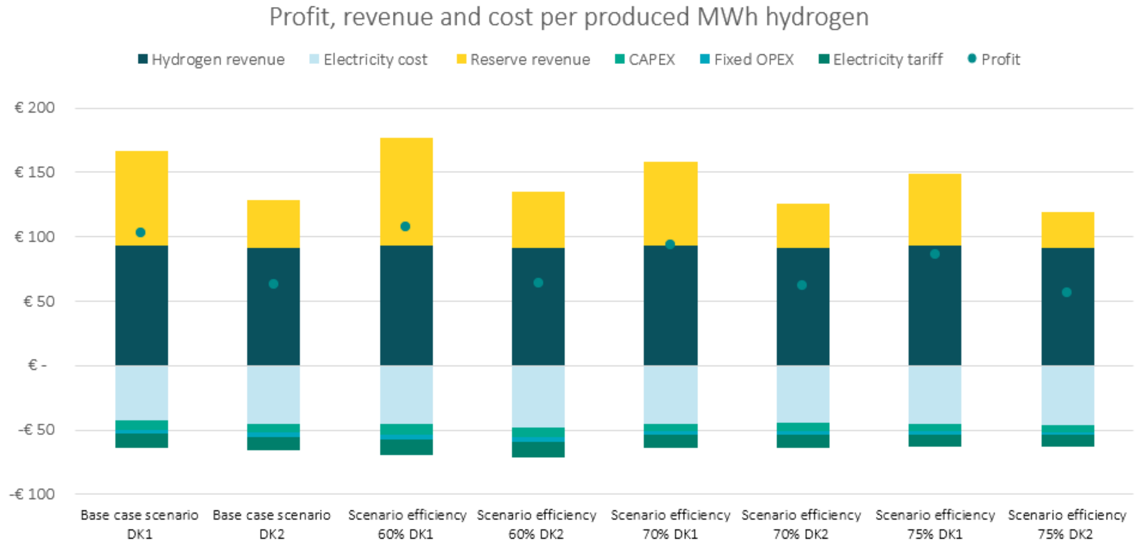




ELECTROLYSIS PLANT'S EFFICIENCY

The efficiency of the electrolysis plant influences the threshold value. Increased efficiency will have a higher hydrogen output and thus cheaper cost of production per unit of hydrogen, resulting in a higher threshold value.

The Figure shows the costs and revenue per produced MWh hydrogen. Here there is a reduction in the revenue from the reserve capacity payment per produced MWh hydrogen. The increased efficiency results in an increased hydrogen production, however, the share of capacity the plant must contribute with in the reserve capacity market, is in this simulation fixed at 30%. Distributed on the individual MWh produced hydrogen the earnings from the reserve capacity market is reduced due to increase in the total hydrogen production but the delivered reserve capacity has not increased correspondingly because the maximum capacity quantity is maintained. The amount of hydrogen produced is thus increased, but as the share of the installed capacity the electrolysis plant offers into the reserve capacity market is maintained for all scenarios, the supply of reserve capacity does not increase.

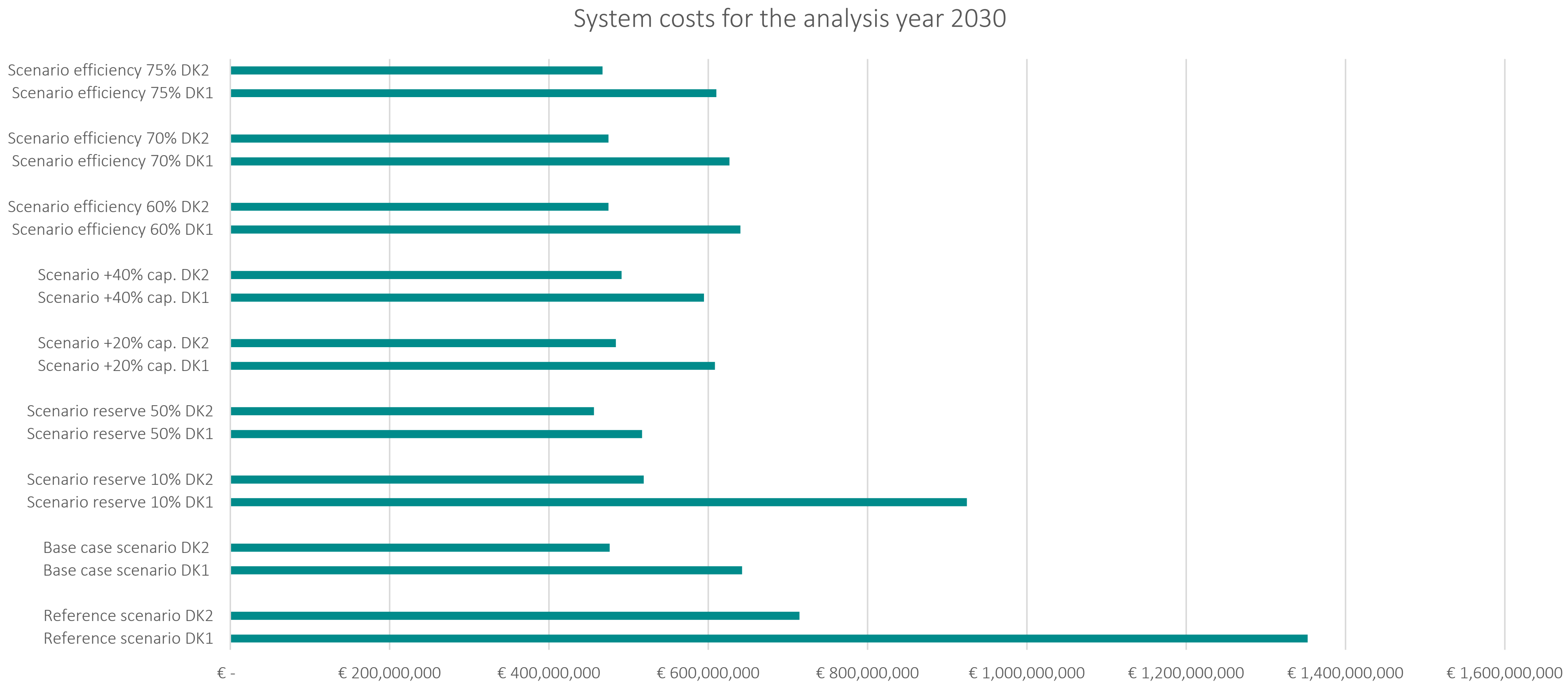


ELECTROLYSIS AS A PLAYER IN THE RESERVE CAPACITY MARKET FROM A SYSTEM PERSPECTIVE

Implementation of electrolysis in the Danish energy system can be of great importance for the development of the green transition. Electrolysis as flexible electricity consumption can potentially create a more dynamic and flexible energy system that is robust to handle large amounts of RE. If, on the other hand, electrolysis plants cannot provide the expected flexibility to the system, there is a risk that it will simply be an expansion of the Danish electricity consumption. The Figure on the next slide shows an overview of how the different scenarios in the sensitivity analysis affect the overall system costs in the simulation year 2030.

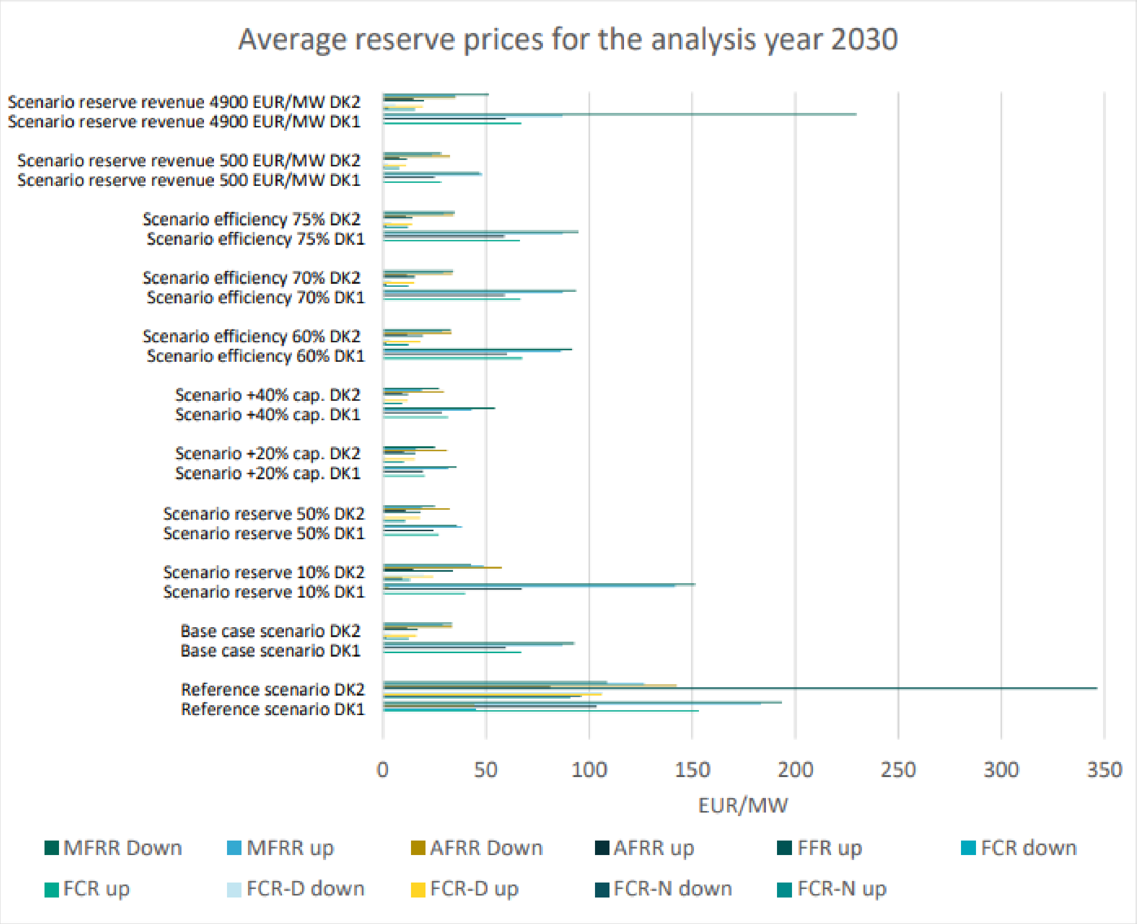
Implementation of electrolysis as a player in the reserve capacity market, reduce the overall system costs significantly, which is seen by the difference in system costs for the reference- and base case scenario. There is a socio-economic benefit from electrolysis participating in the reserve markets in a system perspective. The lowest system cost and thus the best socio-economy choice is the scenario where electrolysis can contribute 50% of its installed capacity in the reserve capacity market. The scenarios with 20% and 40% more installed electrolysis capacity respectively also result in an overall low system cost. Thus, the scenarios with increased capacity also contribute with increased quantity to the reserve capacity market compared to the base case scenario as the share to contribution is maintained at 30%. The increased capacity of electrolysis result in an increased consumption and therefore an increased system cost.

SYSTEM PERSPECTIVE



SYSTEM PERSPECTIVE

The average price in the reserve capacity market is affected by implementation of electrolysis as a player. This is shown in the Figure, where there is a significant reduction in the reserve capacity prices for all reserve types between the reference- and the base case scenario. The share of installed capacity which electrolysis can contribute with, in the reserve capacity market as well as the quantity of installed capacity, has great impact on the average reserve price.

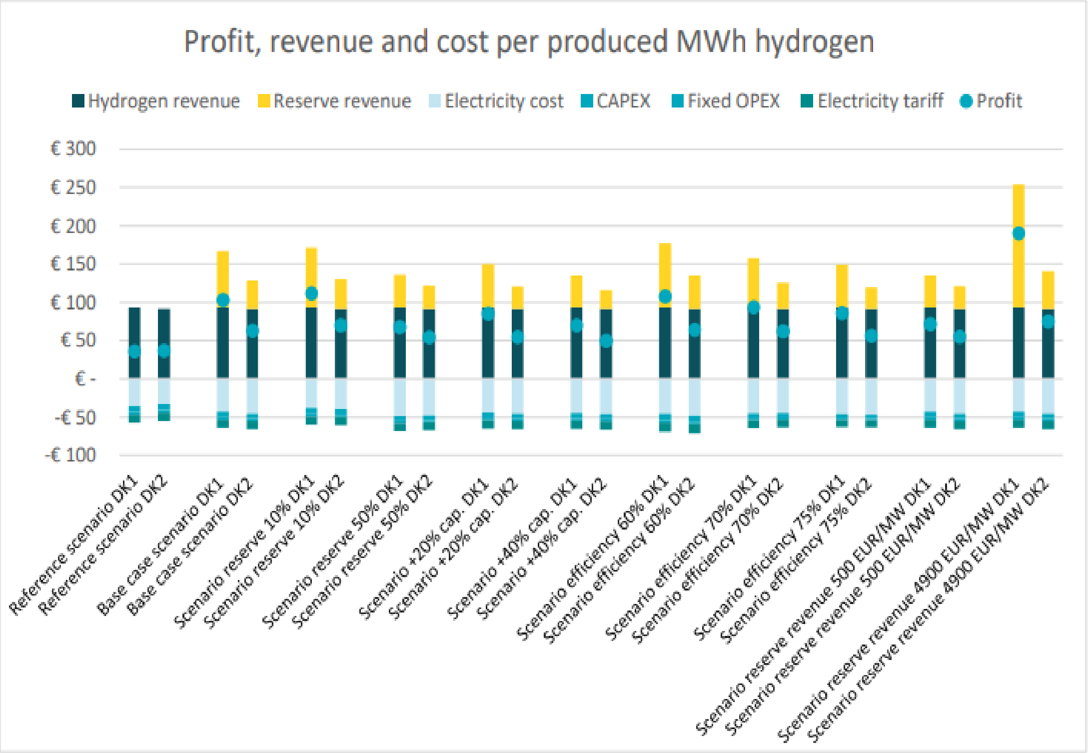


DISCUSSION

The Figure shows the different scenarios in the impact of sensitivity analysis on the electrolysis plant's revenues and costs. From an electrolysis plant perspective, it is interesting to maximize profits per unit produced by minimizing production costs per MWh hydrogen produced.

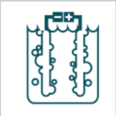
There is a clear economic benefit from participating in the reserve capacity market and supplying reserves. The scenarios where the greatest profit for the electrolysis plant appears is not the scenarios with the lowest system cost and thus the best socio-economy choice. Electrolysis participation in the reserve market reduces the costs of reserve capacity for ancillary services significantly and results in an overall better socio-economy at lower system costs. However, these significantly lower reserve capacity prices result in a lower profit for the simple electrolysis plant.

There is an incentive from participation in the reserve capacity market as it entails a significant economic benefit.



HOW TO ENABLE ELECTROLYSIS PLANTS AS A PLAYER IN THE RESERVE CAPACITY MARKET

The flexibility electrolysis can contribute to the energy system have a value in the reserve capacity market, both for the plant's own business case but also the system's perspective in the form of lower system costs and thereby a better socio-economy.



Investment in more capacity may be necessary for the supply of flexibility and ancillary services to the system if the electrolysis plant is limited by other processes, PPA, etc. It can thus be a prerequisite for the creation of the flexibility from electrolysis plants that an over- dimensioning of the capacity is included already in the establishment phase.

The incentive for electrolysis to provide reserves and contribute with ancillary services is determined by many different factors in the framework conditions under which they will operate in the future. It is therefore important to set the right preconditions for creating the incentive for a flexible operation.