Fimpec

Electricity Market Optimization of Electrolysis-Based Hydrogen Production

Hydrogen Research Forum Finland

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Study background:

Driver: Climate policy & strategies

The European Union aims to produce 10 million tonnes of green hydrogen by 2030. The ambitious hydrogen strategies of the EU and its member states require massive investments in electrolysis-based green hydrogen production. The EU has adopted a delegated regulation for Renewable Fuels of Non-Biological Origin (**RFNBO**), which will set the rules for green hydrogen production in the EU 2030 onwards.

Problem: Economic feasibility

To reach competitive price range, the levelized cost of green hydrogen should drop significantly closer to that of the fossil-based grey hydrogen (~1-3 €/kg).

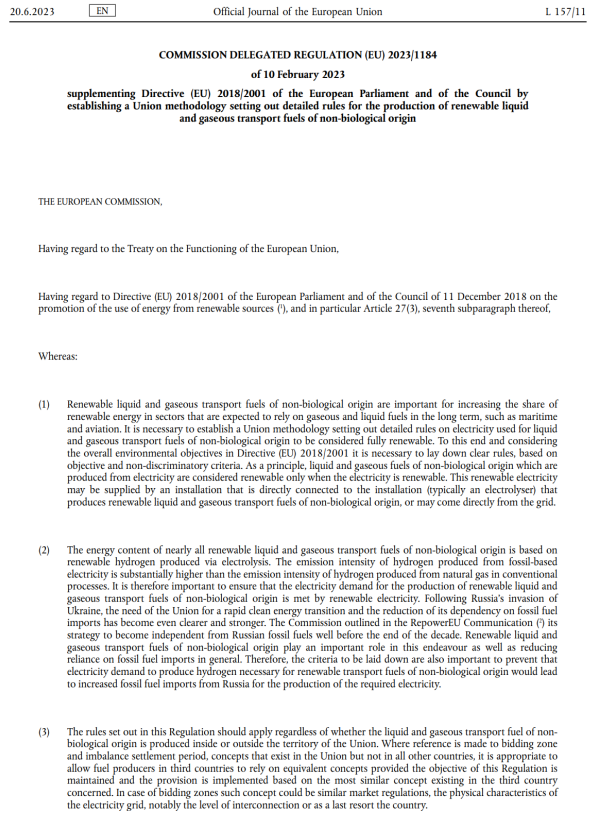
Cost reduction enablers:

- **Technological development**
  - Decreased CAPEX & O&M costs
- **Decreased electricity prices**
  - Country-specific
  - Dependent on investments in renewables
- **System level optimization**
  - Optimized electricity consumption
- **Government subsidies**

Study scope and motivation

Three operating models were implemented and optimized for a 100 MW alkaline electrolyser plant operating in Finland to compare the effects of electricity market participation on the levelized cost of produced hydrogen. The modelled year was 2023.

The results of this study aim to shed light on the economic feasibility of producing green hydrogen in compliance with the EU regulation.



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COMMISSION DELEGATED REGULATION (EU) 2023/1184

of 10 February 2023

supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (1), and in particular Article 27(3), seventh subparagraph thereof,

Whereas:

(1) Renewable liquid and gaseous transport fuels of non-biological origin are important for increasing the share of renewable energy in sectors that are expected to rely on gaseous and liquid fuels in the long term, such as maritime and aviation. It is necessary to establish a Union methodology setting out detailed rules on electricity used for liquid and gaseous transport fuels of non-biological origin to be considered fully renewable. To this end and considering the overall environmental objectives in Directive (EU) 2018/2001 it is necessary to lay down clear rules, based on objective and non-discriminatory criteria. As a principle, liquid and gaseous fuels of non-biological origin which are produced from electricity are considered renewable only when the electricity is renewable. This renewable electricity may be supplied by an installation that is directly connected to the installation (typically an electrolyser) that produces renewable liquid and gaseous transport fuels of non-biological origin, or may come directly from the grid.

(2) The energy content of nearly all renewable liquid and gaseous transport fuels of non-biological origin is based on renewable hydrogen produced via electrolysis. The emission intensity of hydrogen produced from fossil-based electricity is substantially higher than the emission intensity of hydrogen produced from natural gas in conventional processes. It is therefore important to ensure that the electricity demand for the production of renewable liquid and gaseous transport fuels of non-biological origin is met by renewable electricity. Following Russia's invasion of Ukraine, the need of the Union for a rapid clean energy transition and the reduction of its dependency on fossil fuel imports has become even clearer and stronger. The Commission outlined in the RepowerEU Communication (2) its strategy to become independent from Russian fossil fuels well before the end of the decade. Renewable liquid and gaseous transport fuels of non-biological origin play an important role in this endeavour as well as reducing reliance on fossil fuel imports in general. Therefore, the criteria to be laid down are also important to prevent that electricity demand to produce hydrogen necessary for renewable transport fuels of non-biological origin would lead to increased fossil fuel imports from Russia for the production of the required electricity.

(3) The rules set out in this Regulation should apply regardless of whether the liquid and gaseous transport fuel of non-biological origin is produced inside or outside the territory of the Union. Where reference is made to bidding zone and imbalance settlement period, concepts that exist in the Union but not in all other countries, it is appropriate to allow fuel producers in third countries to rely on equivalent concepts provided the objective of this Regulation is maintained and the provision is implemented based on the most similar concept existing in the third country concerned. In case of bidding zones such concept could be similar market regulations, the physical characteristics of the electricity grid, notably the level of interconnection or as a last resort the country.

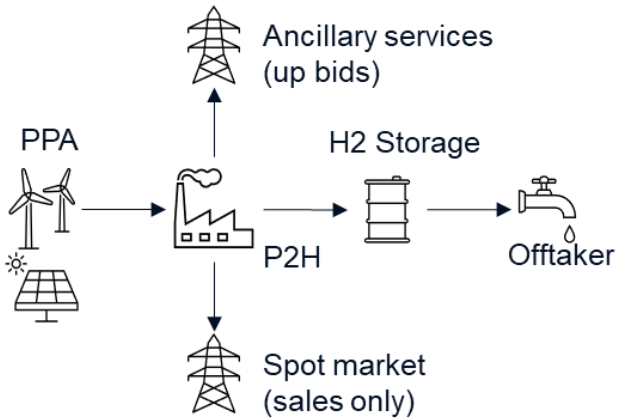
Delegated regulation - 2023/1184 - EN - EUR-Lex (europa.eu)

System configuration

Thesis examines the economic feasibility of three operating models in the Finnish electricity market

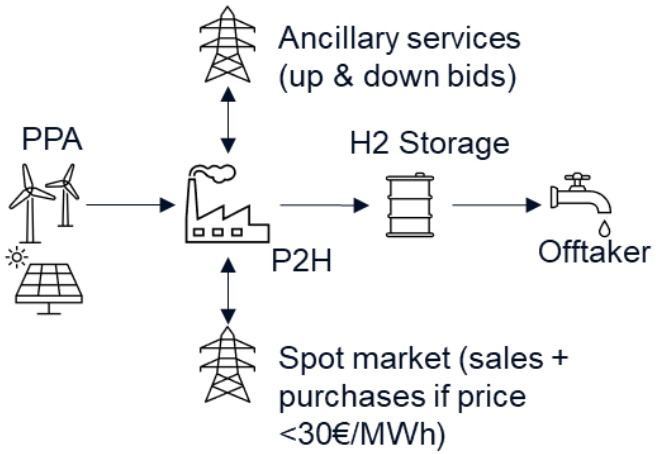
Full Green

- Pay-as-Produced Power Purchase Agreement (PPA) provides electricity to plant
- Electrolyser is responsible for selling excess PPA electricity to spot market
- Electrolyser can provide ancillary services to the reserve market (up-bids)



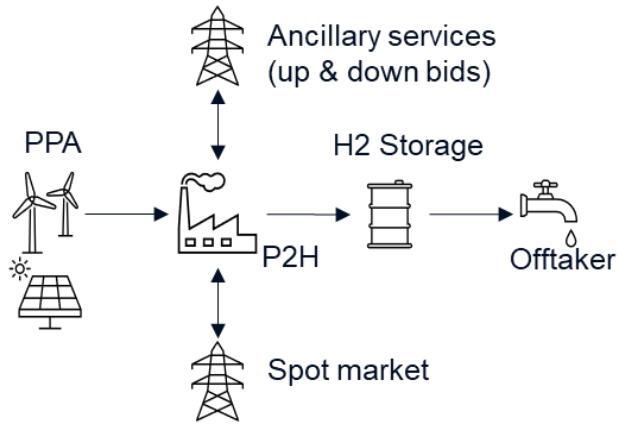
RFNBO compliant

- Pay-as-Produced PPA provides electricity to plant
- Electrolyser is responsible for selling excess PPA electricity to spot market
- If PPA supply is insufficient, load is optimized with additional supply from electricity market if the hourly price is below 30 €/MWh
- Electrolyser can provide ancillary services to the reserve market



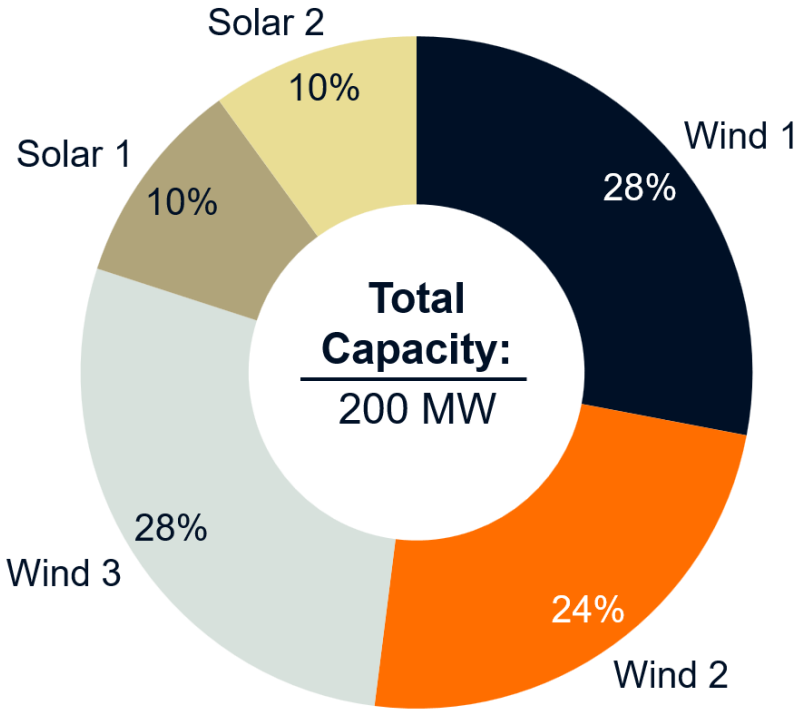
Free Market

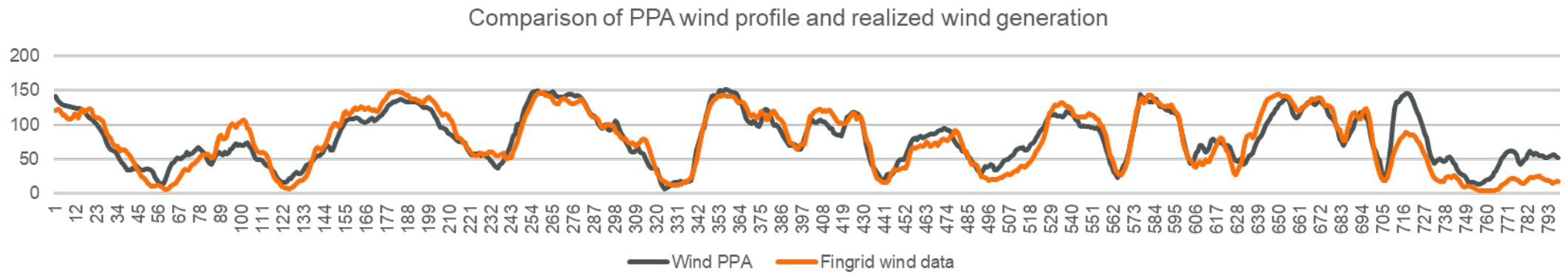
- Pay-as-Produced PPA provides electricity to plant
- Electrolyser is responsible for selling excess PPA electricity to spot market
- If PPA supply is insufficient, load is optimized with additional supply from electricity market with no constraints
- Electrolyser can provide ancillary services to the reserve markets



Power Purchase Agreement (PPA)

- The electrolyser plant procures its electricity with a pay-as-produced PPA portfolio as the consumer must be able to prove the origin of the electricity according to RFNBO regulation.
- In pay-as-produced PPA, consumer (electrolyser) carries the profile risk both with insufficient and excess electricity generation from the PPA producer.
- The modelled PPA consists of 160 MW wind power and 40 MW solar power, totalling to 200 MW of renewable assets.
- Hourly profiles for wind and solar generation for the weather year 2023 were acquired with the Renewables.ninja tool.

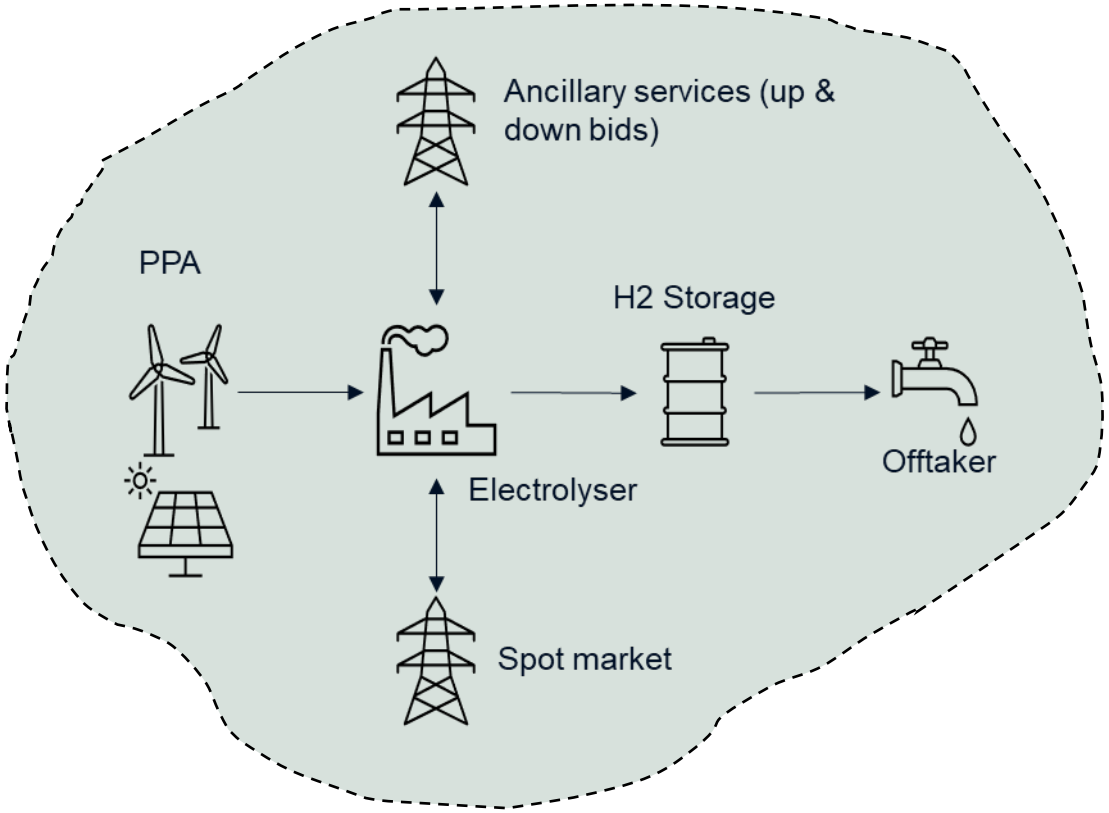




System configuration & optimization

Key details & assumptions

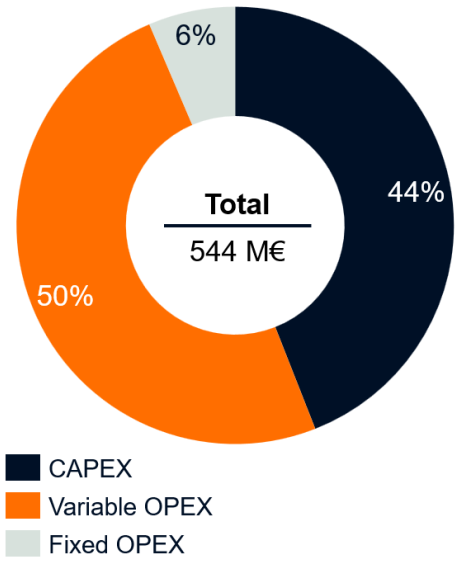
- 100 MW alkaline electrolyser plant with 200 MW Pay-as-produced PPA
  - Surplus electricity sold to spot market. 2023 market data is used in the model. The plant is considered a **price taker.**
- Insufficient electricity supply from PPA is supplemented with electricity from spot market where suitable
  - RFNBO allows electricity procurement when the price of electricity is below 0.36* the price of emission allowance ~30 €/MWh in 2023.
- A hydrogen buffer storage is used to smoothen the supply of hydrogen from the electrolyser plant
- Offtaker allows flexible hydrogen production. electrolyser can optimize its hydrogen production and electricity market & ancillary services participation.
- The electrolyser offers capacity to the automatic and manual frequency restoration reserves (AFRR & MFRR)
- System level optimization was carried out with PLEXOS® energy modelling software

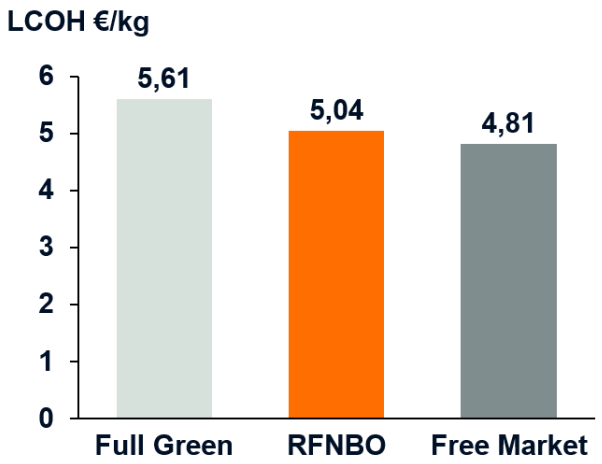


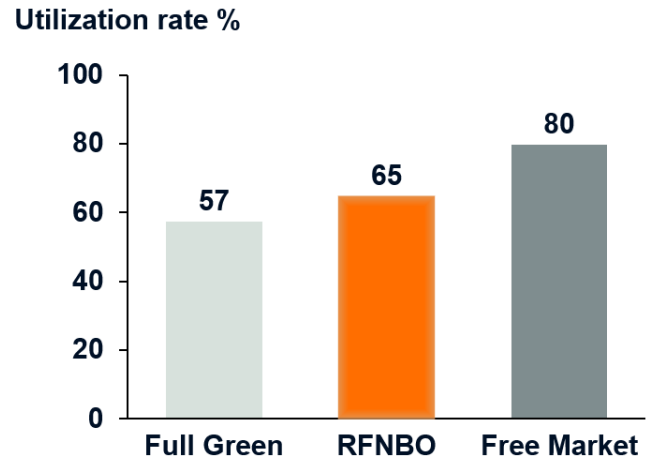
Results

RFNBO compliant hydrogen could cost 5 €/kg in Finland (PPA price 35 €/MWh, WACC 8%)

Discounted lifetime costs (RFNBO)

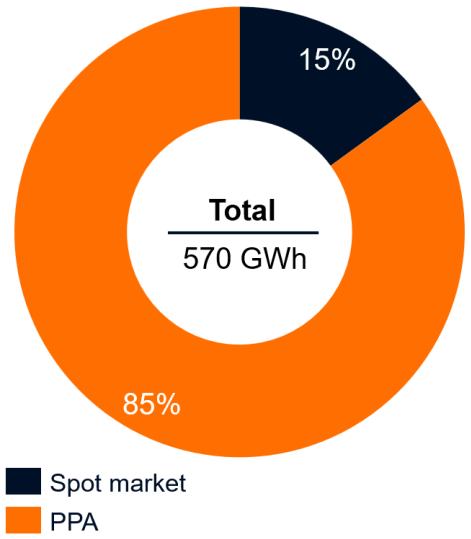


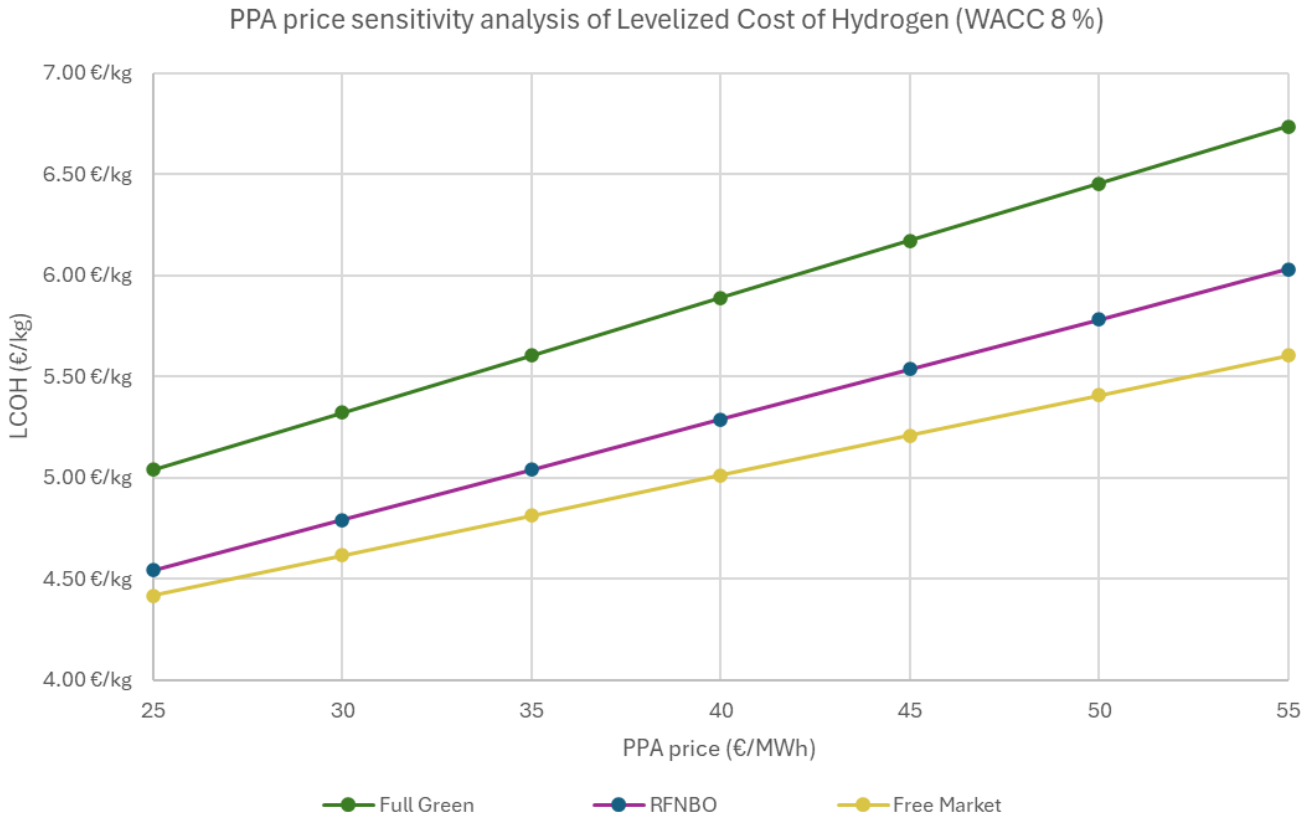




How much can electricity price affect the economic feasibility of green hydrogen production?

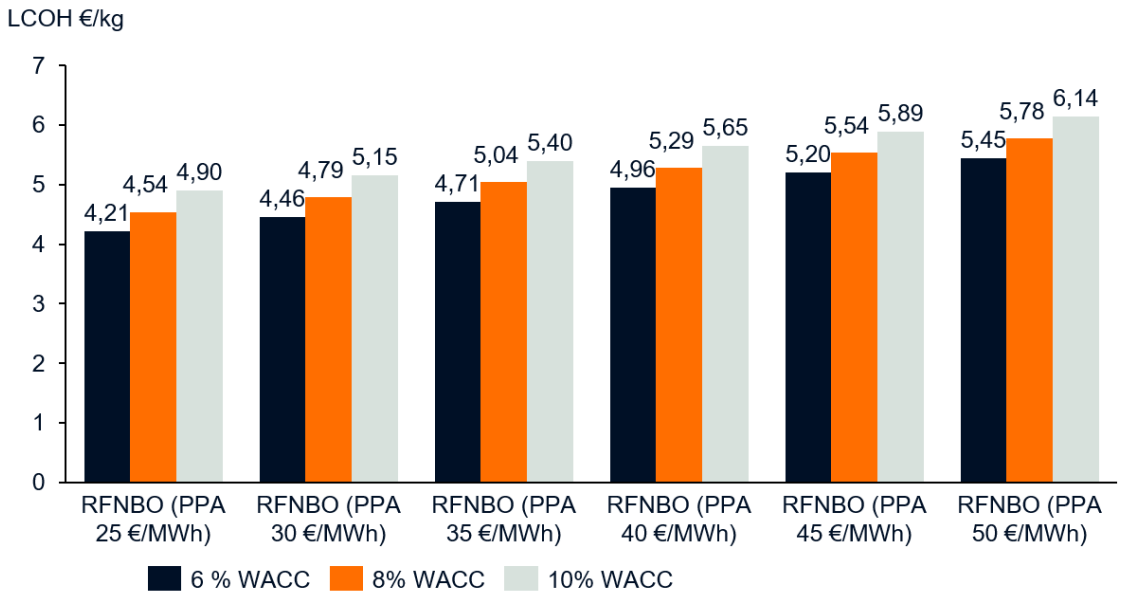
Electricity source of consumed electricity (RFNBO)

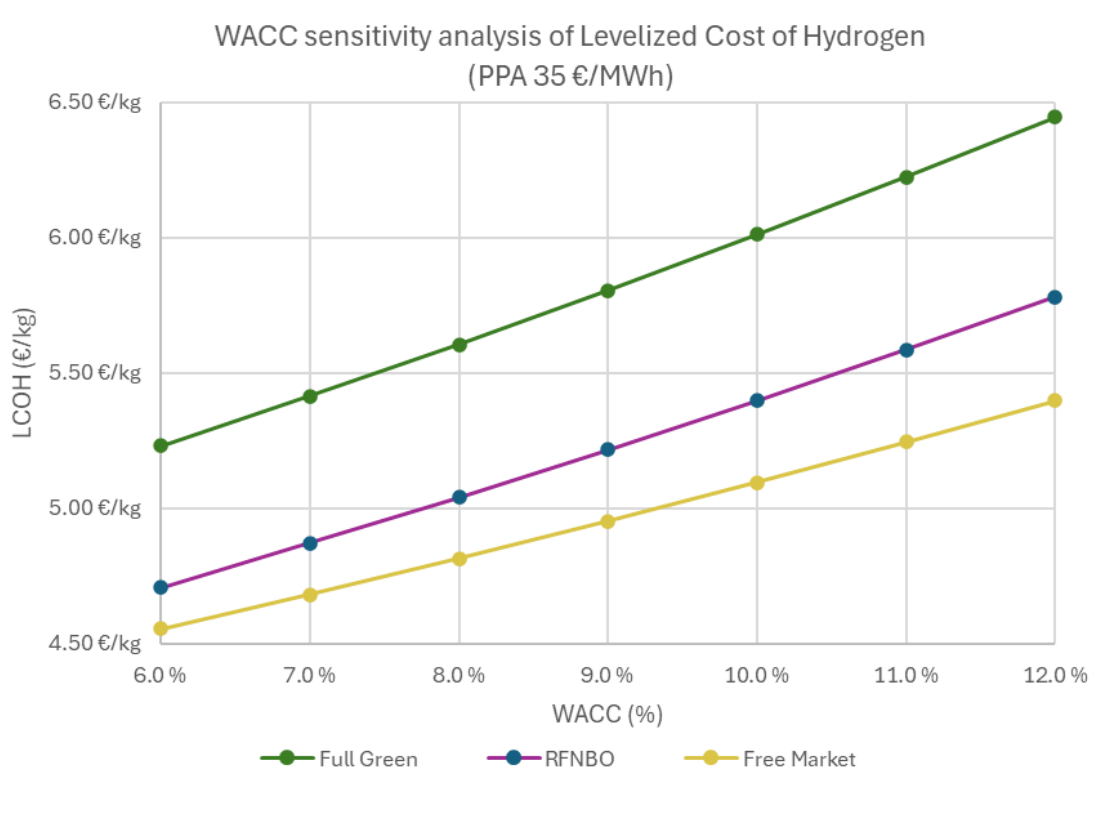




RFNBO hydrogen is expensive even with low WACC and PPA price

WACC & PPA sensitivity analysis (RFNBO model)

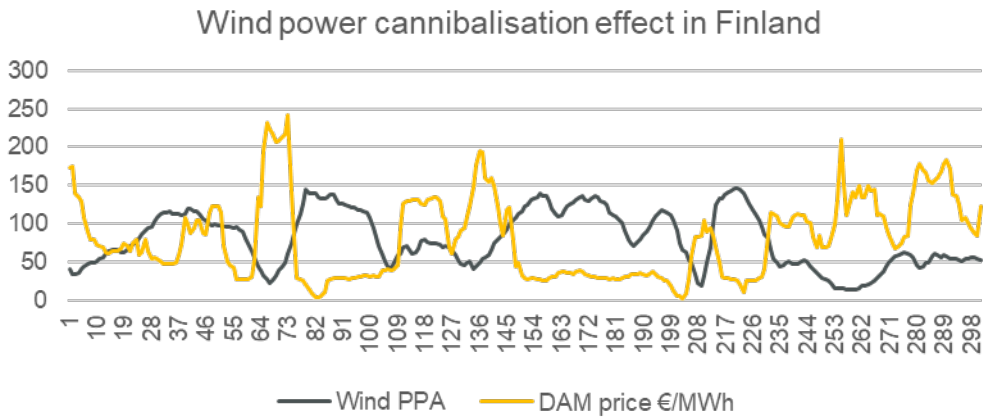


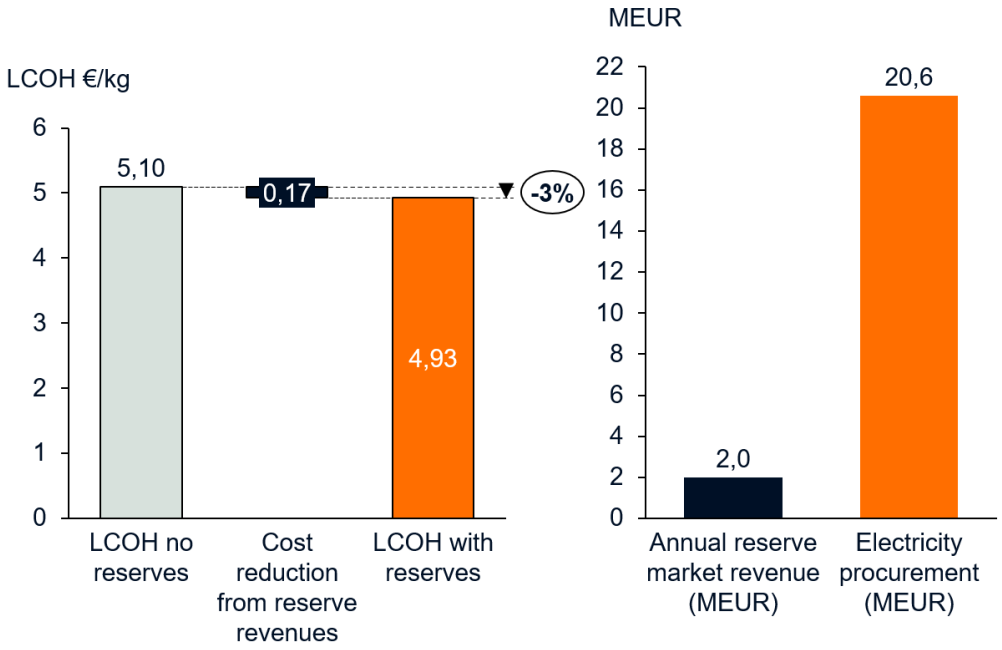


Additional revenue streams reduce LCOH only marginally

Issues with additional revenue streams

- The participation to reserve markets is limited by the PPA due to the cannibalisation effect of renewables. Down-regulation hours often go hand in hand with peak wind power generation, meaning that the electrolyser is running full load and vice versa; the electrolyser cannot ramp down during up-regulation hours if it is not operating at all.
- Surplus electricity sold to spot market suffers from the same issue; when the PPA produces surplus electricity, the spot price is often low due to cannibalisation. The capture price of surplus electricity was 30 €/MWh in the 2023 spot market.





Conclusions and discussion

- The levelized cost of hydrogen for hydrogen produced in Finland was modelled to be 5.04 €/kg for RFNBO compliant hydrogen production. The levelized cost can be decreased if the electrolyser breaks the rules of RFNBO and operates freely in the market. However, hydrogen produced this way would not be “green”.
- The cannibalisation effect of renewable energy in Finland makes it difficult for the balance responsible (electrolyser) to avoid losses from surplus electricity sales if the profile risk of pay-as-produced PPA is only affecting the electricity consumer.
- Even if the electrolyser would receive a subsidy similar to that of Ren-Gas from European Hydrogen bank, the LCOH of produced hydrogen would still be over 4.5 €/kg. To make an efficient transition from grey hydrogen to renewable hydrogen, the price of renewable hydrogen should get closer to that of the fossil-based hydrogen, which is currently around 1-3 €/kg.

Project	Coordinator	Country	Bid volume (kt_H_2 / 10 yrs)	Bid capacity (MWe - megawatts electricity)	Expected GHG avoidance (kt_CO_2 / 10 yrs)	Bid price (EUR/kg)
eNRG Lahti	Nordic Ren-Gas Oy	Finland	122	90	836	0.37
El Alamillo H_2	Benbros Energy S.L.	Spain	65	60	443	0.38
Grey2Green-II	Petrogal S.A.	Portugal	216	200	1477	0.39
HYSENCIA	Angus	Spain	17	35	115	0.48
SKIGA	Skiga	Norway	169	117	1159	0.48
Catalina	Renato Ptx Holdco	Spain	480	500	3284	0.48
MP2X	Madoquapower 2x	Portugal	511	500	3494	0.48

Competitive bidding - European Commission (europa.eu)

Thank you!

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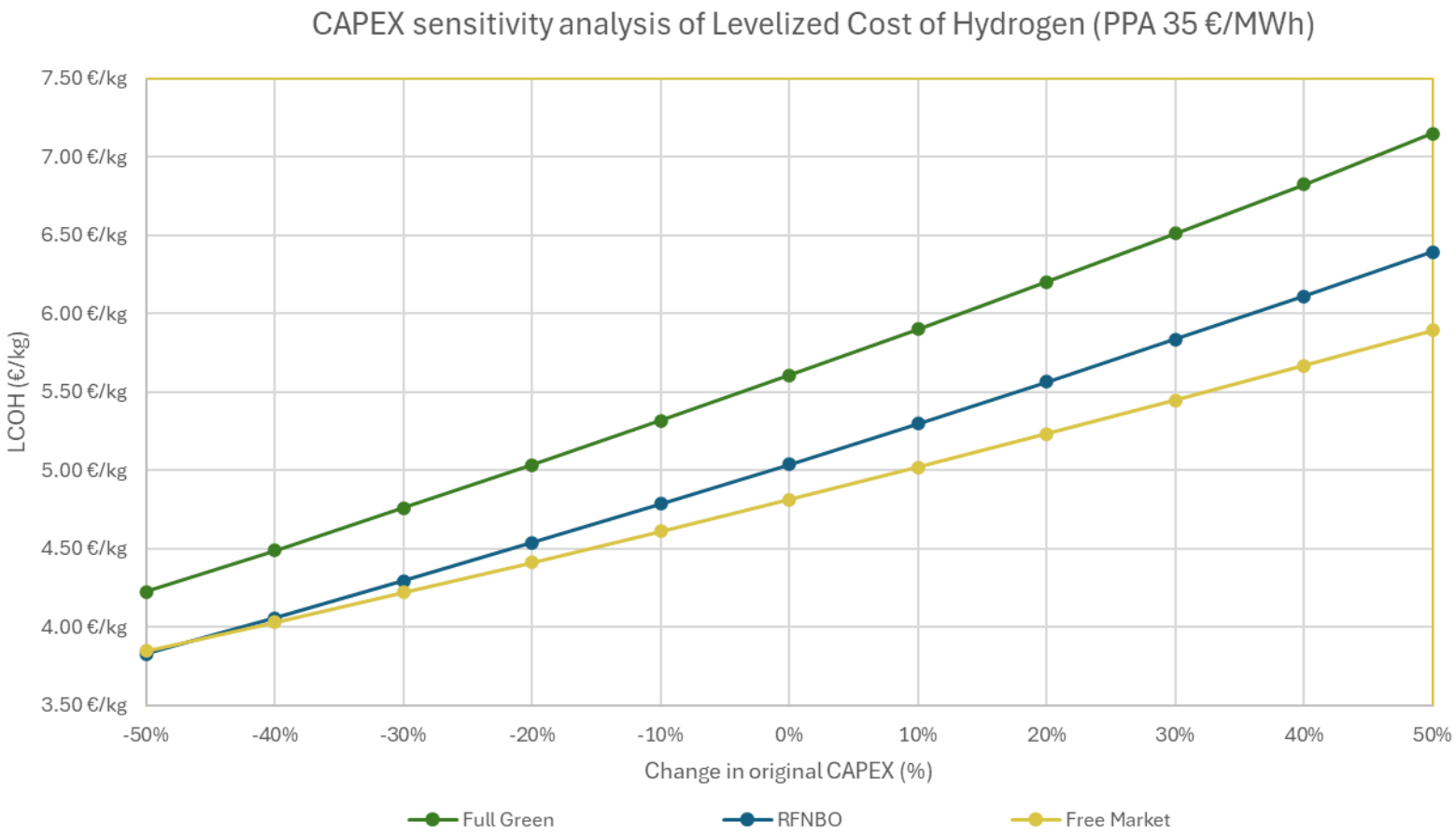
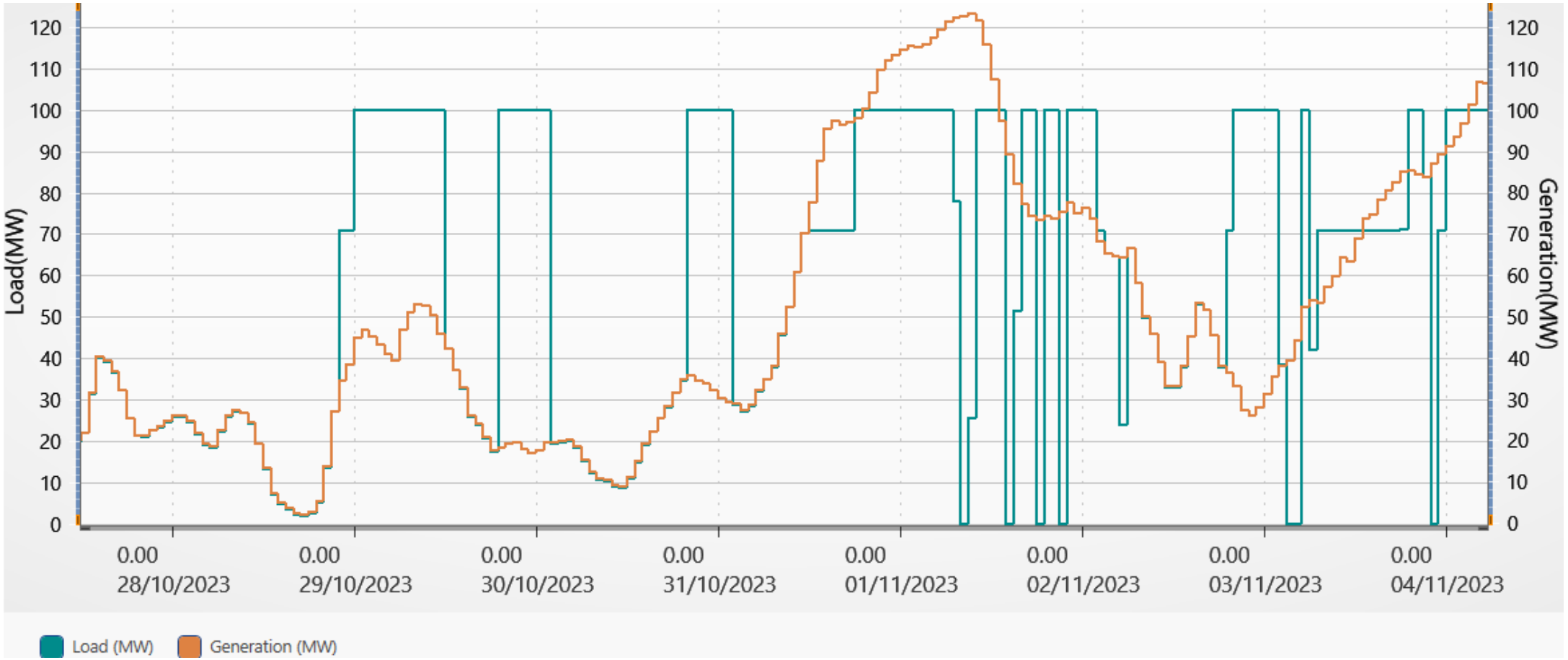
CAPEX sensitivity analysis



PLEXOS Modelling example: Electrolyser Load & PPA Production



PLEXOS Modelling example: Electrolyser Load & Spot Market Purchases