# *SUPPORT MECHANISMS FOR ACCELERATING DECARBONIZATION USING HYDROGEN*

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## Overview

Hydrogen and derived molecules generated through electrolysis can serve as energy carriers and chemical feedstock in a climate-neutral society. These CO2-neutral molecules can make a remarkable contribution to the climate neutrality of the material and chemical industry by the middle of this century. They allow emission-free production of fertilisers and steel, facilitate innovative processes in the chemical industry and may form the basis of sustainable synthetic fuels for shipping and aviation.

Many governments have announced ambitious hydrogen strategies, and therefore want to accelerate the deployment of renewable production and end-use applications. Since the zero-carbon hydrogen production technologies are not yet competitive with the traditional hydrogen production route, governments wish to support the required technologies to produce hydrogen sustainably and enable a carbon-neutral industry.

Previous research has studied the implementation of policies to support renewable electricity generation and the trade-offs between capacity- and energy-based subsidies (Özdemir et al., 2020). Research dedicated to bringing this knowledge to clean hydrogen production, while accounting for its differences, is currently sparse. Large-scale dedicated hydrogen support may nonetheless profoundly impact liberalised energy markets. For example, subsidising hydrogen production may increase wholesale electricity prices, contrary to renewable electricity support. The degree to which this effect will manifest depends on the selected policy instrument. Because electrolyser technologies are dispatchable, one should beware of any potentially distorting influence of these policy instruments on the operational decisions of hydrogen installations. The discussion is further complicated by the fact that different electrolyser technologies are available with different capital expenditures (CAPEX) and efficiencies. An optimal technology mix should address the system's needs: low-CAPEX variants with a poorer efficiency could for instance be preferred if renewable curtailment is prevalent. As has been shown for renewable electricity instruments, however, certain subsidy designs might distort the optimal technology mix. Another policy which could be applied to clean hydrogen production are Carbon Contracts for Difference (Richstein, 2017). While the cost of this policy mechanism has been studied, and a comparison with other policy instruments has been made (Vogl et al., 2021), research on the impact on cap-and-trade systems (e.g., EU ETS) and electricity markets is lacking.

To investigate the impact of the aforementioned policy instruments on energy markets and cap-and-trade systems, we develop a state-of-the-art model that captures the interactions between hydrogen, electricity and CO2 emission markets which can be used to simulate the effect of different hydrogen support policies. Key questions will be addressed such as: what is the price effect on carbon- and electricity markets? How is the subsidy pass-through of the hydrogen support to hydrogen producers, hydrogen consumers and electricity producers? Which technologies are promoted by different policies? How much does a given policy increase electricity prices for consumers?

The compared support mechanisms are: i) A capacity-based investment subsidy (EUR/MW), ii) A quantity-based premium (EUR/MWh), iii) a hybrid quantity- and capacity-based mechanism which is a variant of a quantity-based premium that limits the amount of compensation according to a predetermined ratio of MWh per MW of installed capacity (Özdemir et al., 2020). While originally proposed in the context of RES support, we see particular use for this instrument in supporting hydrogen since the compensation limit can prohibit the electrolyser from being dispatched at moments with higher electricity prices. And iv) A Carbon Contract for Difference that guarantees the investors in carbon-neutral hydrogen a fixed carbon price (EUR/tCO2) for the duration of their investment. The remuneration is determined according to a benchmark linked to the carbon intensity of the total hydrogen production.

## Methods

To address our research questions we will employ the equilibrium model formulated as a mixed complementary problem and solution strategy developed by Bruninx et al. (2021). The model comprises of:

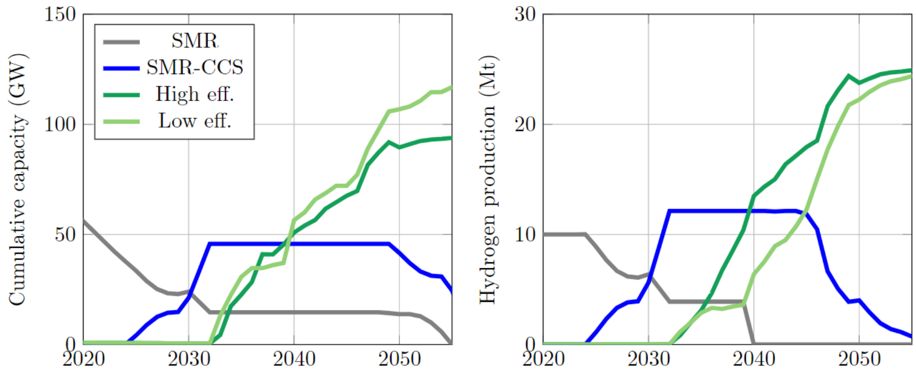
- An electricity market in which investors in gas-fired generation, wind, solar, and nuclear compete and optimize their operation considering the variable generation of renewables and demand for electricity.

- A hydrogen market in which investors in different renewable hydrogen production technologies compete with traditional steam methane reforming (SMR) technology. Two electrolysis technologies are considered: a highly efficient one with higher CAPEX and a low efficient variant with a lower CAPEX. We furthermore include SMR equipped with carbon capture and storage (CCS).

- A cap-and-trade emission scheme in which the fossil-based electricity actors compete with SMR technology and a competitive fringe. The fringe has to decide either to buy emission permits or to bear the abatement cost, which is modelled as quadratically increasing. This actor represents the remainder of the industrial demand for emission allowances. Emission permits are bankable between all considered years 2020-2060 and borrowing is prohibited.

## Results

In our reference case without considering any support policies, we observe a gradual roll-out of SMR with CCS followed by the uptake of electrolysis-based hydrogen production and a gradual phase-out of legacy SMR production. Even though the low-efficient electrolysis solution has a 25% lower CAPEX than the highly efficient choice, they are both being installed.




Our preliminary assessment concerning the impact of policy schemes shows that both capacity and quantity-based instruments increase the installed capacity of carbon-neutral hydrogen technologies and can accelerate investments in these technologies. We observe that a capacity-based solution achieves this without affecting the operation of carbon-neutral technologies. However, a capacity-based solution does select technologies with a low CAPEX and does not encourage any additional learning effects into the higher efficient solutions.

## Conclusions

Having a mix of technologies in place to provide carbon-neutral hydrogen will be beneficial rather than favouring a single technology. Both capacity-based and quantity-based subsidy mechanisms can be used to increase the investment in electrolyser capacity. Care should be taken about how the chosen policy mechanisms affect the price signal on which electrolysers will base their dispatch since it may negatively affect economic efficiency. Subsidy schemes that support capacity generally distort the dispatch of electrolysers less compared to mechanisms that give a premium on produced quantity since they do not artificially increase the willingness to pay for electricity of agents operating electrolyser installations. Technologies with a lower installation cost benefit from mechanisms that remunerate capacity, while the more efficient technologies are cheaper to operate and may therefore be more cost-effective.

## References

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