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Support Mechanisms for Hydrogen: Interactions and Distortions of Different Instruments

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Introduction

Hydrogen and further derived molecules generated through electrolysis can serve as energy carriers in a climate-neutral society. Such CO_2 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 be 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 needed technologies to produce hydrogen sustainably and enable a carbon-neutral industry.

Some academic literature exists on the effects of hydrogen subsidy mechanisms [7] and the possible interactions it may cause with existing climate policy, such as carbon prices [6]. Little research dedicated to the design of hydrogen subsidy mechanisms currently exists. However, it is known from previous research that has studied the implementation of subsidy mechanisms for renewable electricity generation that such interventions in energy markets may lead to distortions in the dispatch of generation assets [4, 8] and distortions in technology choice [9, 3, 5].

To investigate the impact of hydrogen subsidy mechanisms on energy markets and cap-and-trade systems, we extend the state-of-the-art long-term equilibrium model that captures the interactions between hydrogen, electricity and emission markets developed by [2] which can be used to simulate the effect of different hydrogen support mechanisms. We compare capacity-based subsidy mechanisms (EUR/MW) with three quantity-based mechanisms (EUR/MWh): A tradable certificate system (QT), a fixed-premium (FP) and hydrogen contract for difference (CfD).

Methodology

To address our research questions we will employ an equilibrium model presented as a mixed complementary problem. The model comprises three different markets:

- 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 each other and with the traditional steam methane reforming (SMR) technology. Two electrolysis technologies are considered, i.e., a highly efficient (low OPEX, high CAPEX) and low efficient variant (high OPEX, low CAPEX), as well as SMR with carbon capture and storage (CCS) and hydrogen import.
- A cap-and-trade system for CO_2 emissions in which the fossil-based electricity actors compete with SMR technology and a competitive fringe. The fringe has to decide to buy emission permits or bear the abatement cost, which is modelled as a quadratically increasing function of abatement. This actor represents the remainder of the industrial demand for emission allowances. Emission permits are bankable between all compliance years 2020-2050 and borrowing is prohibited.

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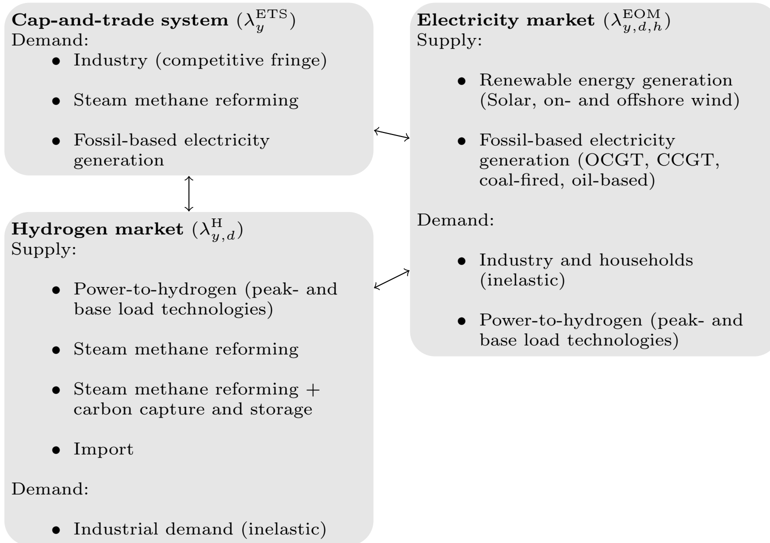


Figure 1: Block diagram model

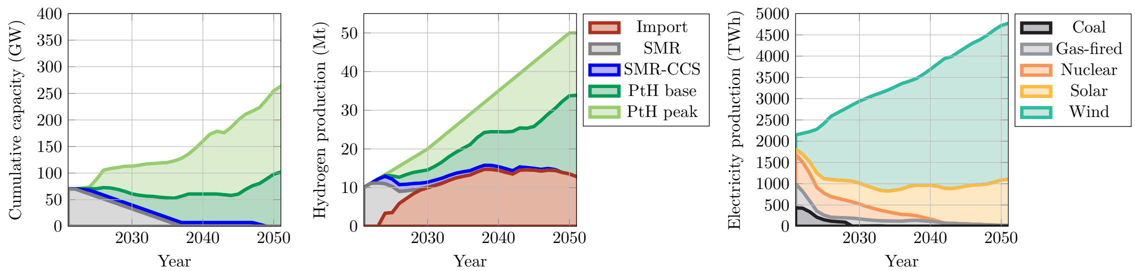


Figure 2: Hydrogen production, hydrogen production capacity investments and source of electricity production in the reference case

We solve the equilibrium model using the distributed Alternating Direction Method of Multipliers (ADMM) [1] which links the different markets: electricity, emissions and hydrogen through a set of coupling constraints in which the actions of the different actors are combined to find the equilibrium prices. As such, the interactions between the different markets can be studied. An overview of the actors in these markets and the interactions between them is provided in Figure 1. We conduct a case study using a power system inspired by the European system, recent electrolyser cost estimates, and a cap-and-trade system that is inspired by EU-ETS. The cap-and-trade model is implemented following [2] without considering the Market Stability Reserve.

Results

In Figure 2 the results of the multi-year equilibrium model are given in the reference case, which does not consider any hydrogen support mechanisms. In the hydrogen sector, no new investments in SMR occur and SMR-based hydrogen production is gradually phased out in favor of import and electrolytic hydrogen. By 2030 8.6 Mt is produced by PtH out of the 10 Mt domestic hydrogen production. SMR equipped with CCS contributes 1.3 Mt in 2030. We observe that, similarly to power systems, an optimal mix of low-CAPEX high-efficient and high-CAPEX low-efficient PtH techologies arises. In the power sector, 2416 TWh is supplied by solar and wind, and 522 TWh by non-renewable generation in 2030.

In Figure 3 a load duration curve of the hydrogen production is shown, which shows the dispatch of the peak and base PtH technology. Each value represents one hour and they are sorted from high to low profit margin. Their profit margin (i.e. operation profit) is given by the difference between the hydrogen and electricity prices during that hour, considering the efficiency of the considered technology variant. It can be observed that technologies are fully dispatched when it is economical. During the hours that the technologies are partially dispatched, they are price-setting in the electricity market. This can be seen by

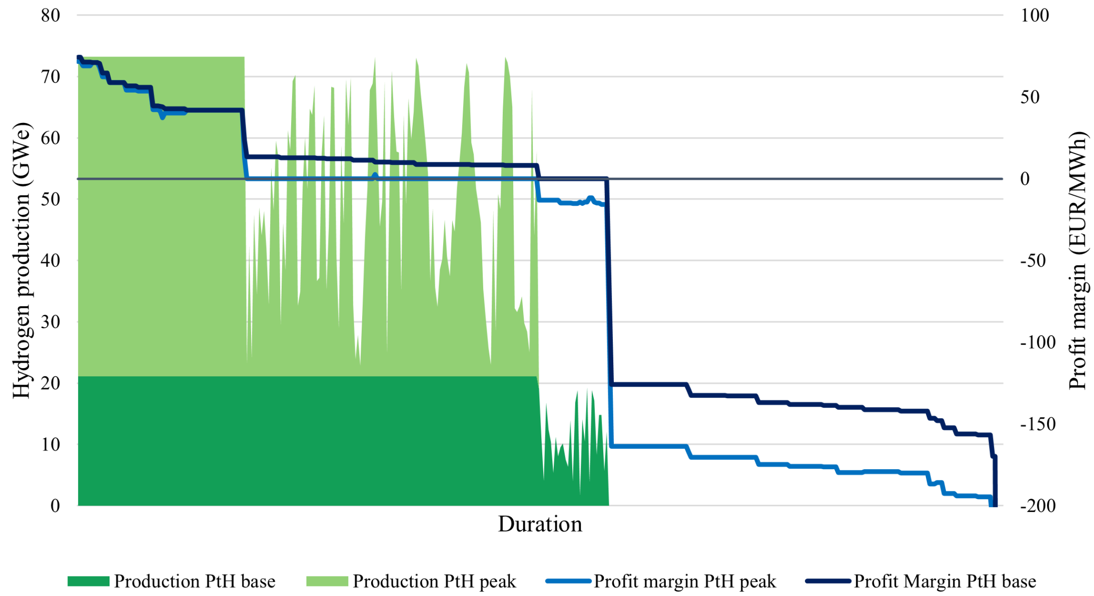
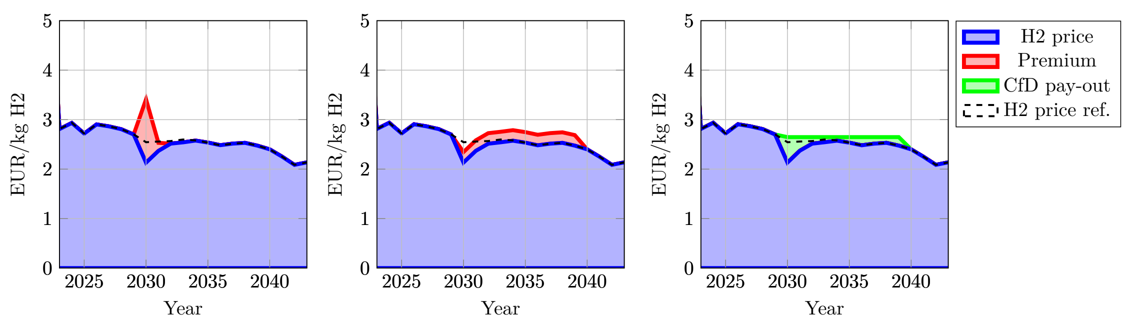


Figure 3: Hydrogen production duration curve of the hydrogen sector that shows the dispatch of the peak and base PtH technology as well as their profit margin.



(a) Quantity target (b) Fixed premium (c) H2 CfD

Figure 4: Hydrogen market revenue and policy subsidy in the case of (a) a quantity target attained through a tradable certificate system, (b) an auctioned fixed premium and (c) an auctioned hydrogen contract for difference; that achieve 10 Mt electrolytic hydrogen target

the fact that they have a zero profit margin during these hours. This occurs during a significant number of operating hours.

In Figure 4 it is visualised how such multi-year instruments are different from a quantity target attained through a tradable certificate system (QT), and what the difference is between a FP and CfD. In the case of a quantity target the premium is determined each year such that the 10 Mt target is met in every year from 2030 onwards. Therefore, support is concentrated in the years when total hydrogen demand is low and the target is therefore strict. In the case of a FP the support is divided uniform over the duration of the contract.

In Figure 5, four different policies are shown that all achieve 10 Mt of electrolytic hydrogen production. While the capacity target produces the imposed 10 Mt of electrolytic hydrogen from the peak and base load technology at roughly the same proportion as the quantity target, it does install more peak capacity than the quantity target. This indicates that this policy has a selection bias towards the cheaper peak unit, which was expected.

In Figure 6, the impact on the power system is shown. In the left figure, the changes in production source are shown compared to the reference scenario without a target. Reaching the 10 Mt target of electrolytic hydrogen requires an additional 72 TWh electricity in case of a capacity target, 59 TWh in case of a quantity target, 62 TWh in case of a FP or CfD; these differences can be explained by the choice

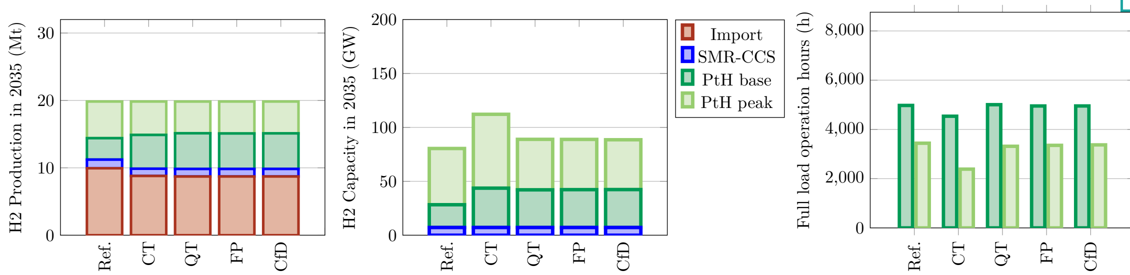


Figure 5: Impact of capacity target (CT), quantity targets (QT), fixed premium (FP) and hydrogen contract for difference (CfD) on hydrogen production and capacity investment in the hydrogen sector.

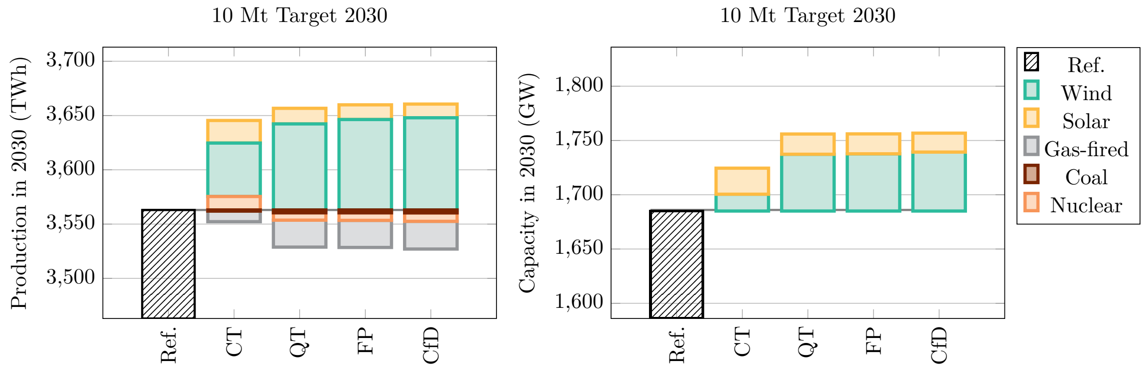


Figure 6: Impact of capacity target (CT), quantity targets (QT), fixed premium (FP) and hydrogen contract for difference (CfD) on electricity production and capacity investment in the power sector, compared to no target

of the peak PtH technology which has a lower efficiency and hence increases electricity demand. In the right figure, the changes in investment decisions are shown. Here it can be seen that a capacity target can obtain 10 Mt of electrolytic hydrogen with less renewables than the quantity target, which can be explained by less curtailment that occurs because electricity can be consumed by producing hydrogen. It can be observed that the PtH targets decrease production of gas-fired generation, this can be explained by the increased attractiveness of renewables when dispatchable load PtH is added to the system. The effect is more prominent for quantity targets than for capacity targets, due to the fact that a QT requires more installed capacity in renewables, which leads to more renewable electricity generation during peak hours, when PtH do not operate.

Discussion

Economic justifications for hydrogen subsidization go beyond climate damages and can be grounded in learning effects and the inability of risk averse investors to transfer their risk to parties that can take on the risk efficiently. Hydrogen markets in particular are still nascent and limited hedging possibilities exist. They typically take either the form of a capacity-based payment (EUR/MW) or quantity-based (EUR/MWh), examples of both approaches exist although there seems to be a trend towards quantity-based mechanism. The two most prominent mechanisms to date, the US Inflation Reduction Act and the EU hydrogen bank, employ quantity-based hydrogen support.

When comparing the mechanisms for their impact on energy markets, we did not find strong distortions to the operational decisions of the actors involved. It became apparent that achieving the 10 Mt target through a CT, requires less investment into renewables, since the higher peak PtH capacity allows the PtH facilities to capture more renewable energy and curtail less. All subsidy mechanisms tend to decrease fossil-based electricity generation because investment into renewables becomes more attractive when more dispatchable load is added to the system.

Conclusion

To conclude, we investigated the impact of hydrogen subsidy mechanisms on energy markets and cap-and-trade systems using a long-term equilibrium model that captures the interactions between hydrogen, electricity and emission markets. We compare capacity-based subsidy mechanisms with three quantity-based mechanisms: a tradable certificate system (QT), a fixed-premium (FP) and a hydrogen contract for difference (CfD). We observed that the choice of the mechanism has implications on the renewable capacity and displacement of gas-fired generation in the power sector.

In the full paper, we will focus on system costs as well as a metric to compare the different subsidy mechanisms. We suspect FP and CfD to offer better risk mitigation than a QT, to study that we plan to look into modelling under uncertainty.

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