THE GLOBAL HYDROGEN MARKET 2050 – A MODEL-BASED COMPARISON OF PATHWAYS AND POLICY CONSTRAINTS

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Overview
Hydrogen is expected to play a major role in decarbonizing energy systems in the future. In this context, many regions and individual countries are preparing hydrogen strategies for a gradual rollout of new applications, infrastructure, and technical and institutional rules for governing future market segments. The objective of this paper is to develop a numerical model for the global hydrogen market, and to provide estimates for future hydrogen consumption, trading, and production until 2050. By identifying technical and political constraints, the paper provides insights into different hydrogen futures, and their respective quantification.

Methods
We develop a global hydrogen model ("GH2-MOD"), inspired by the Global Gas Model family (Egging, Holz, and Gabriel 2010; Egging and Holz 2019). GH2-MOD is a mixed complementarity model (MCP) of the hydrogen market. Modeled with their respective objective functions are the following players: producers, traders, liquefiers, regasifiers, storage operators, pipeline operators and transmission system operators. Producers are considered to maximize discounted profits, which are the result of subtracting production costs from revenues. Liquefiers maximize their profits by buying hydrogen from producers in the same region and selling to regasifiers in other regions; traders buy hydrogen from producers and sell it to the final demand sectors locally and abroad (transport via pipelines). Regasifiers maximize profits of purchasing hydrogen from liquefiers and selling it to the demand sectors in their respective region. Storage operators maximize profits from buying hydrogen at one period and reselling at a later time. Pipeline operators assign available capacities of pipelines to traders wanting to export hydrogen, while the transmission system operator is responsible for the optimal expansion of the pipeline network. Furthermore, it is possible to consider hydrogen transport as ammonia with additional players for hydrogenation (to produce ammonia) and dehydrogenation (to obtain hydrogen). The model structure is depicted in Figure 1.

In addition to the model development, we have established a set of data on technologies, costs, demand, and infrastructure, both for the point of inception (2020), and until the target year 2050. This database includes information from publicly available sources, as well as our own estimates and results from colleagues, e.g. the GENeSYS-MOD global model (Löffler et al. 2017; Burandt, Löffler, and Hainsch 2018; Auer et al. 2020; Hainsch et al. 2020).

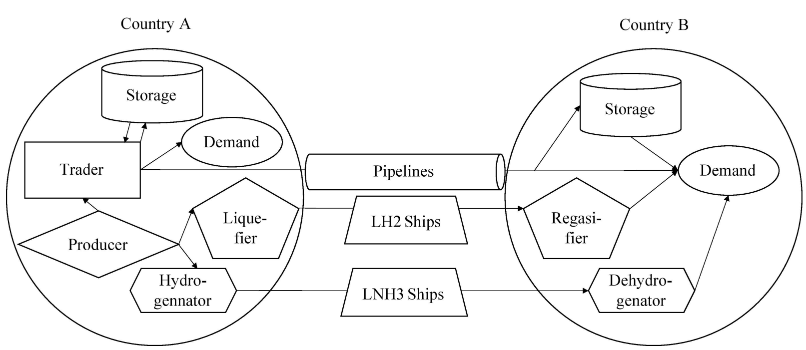

Figure 1: GH2-MOD value chain and actors (including ammonia shipping).

(Preliminary) Results

Model runs are currently under way for a base case ("*business-as-usual*", BAU), and various other scenarios. The BAU-case features full decarbonization of the global energy system by 2050, and the development of a renewable energy system, in the spirit of the GENeSYS-MOD global scenarios. The transformation process includes the gradual phasing out of fossil fuels and nuclear power, following a carbon budget approach.

We also run an alternative scenario "*fossil hydrogen*", which is a scenario where the world decarbonizes incompletely, and where therefore hydrogen from fossil fuels can still be traded on a global scale.In addition, all scenarios will be run with differing assumptions regarding the exertion of market power, varying between perfect competition and an oligopolistic market structure à la Cournot.

The scenarios are compared with respect to quantities produced, traded, and consumed, as well as prices, infrastructure investments and more.

Conclusions

Decarbonization pathways are associated with lots of uncertainties, and the future role of hydrogen is one of them. Many regions and individual countries are preparing hydrogen strategies for a gradual rollout of new applications. This research paper helps to understand the major driving forces of such a future hydrogen economy. Our goal is to provide profound quantitative insights into the global trade of hydrogen. Our method of choice is a numerical equilibrium model, formulated as an MCP, where the value chain is disaggregated into separate players each with their respective objective functions. Considered as individual players are producers, traders, liquefiers, regasifiers storage operators, pipeline operators and transmission system operators.

This approach allows us to gain quantitative results regarding inter alia quantities produced, traded and consumed, as well as prices, and investments in the regions considered. Running multiple scenarios on decarbonization as well as the exertion of market power should help to spell out different hydrogen futures, both for industry experts and policy makers.

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