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Ramping Up Low-Emission Hydrogen Imports to Europe: Case Studies and Transition Pathways

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Overview
For the energy transition hydrogen and hydrogen carriers will become an important building block to defossilize many sectors such as energy, heating, industry and mobility. In light of the urgent global need to reduce greenhouse gas emissions and combat climate change, hydrogen emerges as a potent alternative to fossil fuels. According to the European Union the production target for hydrogen in 2030 is 10 million tons and additionally 10 million tons of hydrogen imports, of which Norway for example is predicted to be a significant part of. This study presents an analysis of the transition from natural gas to hydrogen (blue and green) as a pivotal move towards decarbonizing Europe's energy supply, with a specific case study focus on Norway and Algeria's role as a primary energy exporter and as a suitable representative of further energy exporting countries. This research spans a significant timeframe, from 2025 to 2050, marking critical decades in the energy transition when the majority of Europe pledged to be carbon neutral. We assess the attractiveness of exporting low-carbon and renewable hydrogen in competition to natural gas to Europe through various possible transportation modes (by retrofitted natural gas pipelines, new purpose-built pipelines or ammonia as a hydrogen carrier) in this transition period. We analyze this transitioning from natural gas exports to hydrogen exports under different scenarios in a mixed-integer linear optimization model. Our results show, that this transition from an energy exporter perspective will take place under very different timeframes from natural gas to low-carbon or/and renewable hydrogen and that the switching times are heavily dependent on factors such as CO2 pricing, cost degressions and regional factors such as upstream emissions.
Methods
For the analysis in this research, we created a MIP model, solving with Gurobi. The objective function in this model is to minimize the total sum of annual system costs for the modeled country's energy exports which includes the export of natural gas, blue hydrogen and green hydrogen over the whole timeframe from 2025 to 2050. The optimization model incorporates a variety of constraints, for example transport capacities and the inherent limitations in retrofitting existing natural gas pipelines for hydrogen transport. We also integrated a detailed sensitivity analysis to analyze the impact of pivotal parameters, including but not limited to, natural gas cost, CO2 pricing, upstream emission impact (which are influenced by CO2 pricing and region), and various capital costs. Generally, we presume a constant annual export of energy that can be composed of natural gas or hydrogen. Alternatively, to investigate the dynamics between low-carbon and renewable hydrogen only, an increasing hydrogen demand from 2025 to 2050 can be assumed. The composition of energy exports is calculated endogenously as well as all required capacities along the supply chain. The model is also applicable to further countries and hydrogen derivatives.
Results
Key results highlight the feasibility and economic viability of transitioning from natural gas to hydrogen, with a specific emphasis on Norway and Algeria in a case study. The analysis reveals that while the transition is feasible under a range of scenarios, it is particularly sensitive to fluctuations in natural gas cost, CO2 pricing, and the associated capital costs of electrolyzers and renewable electricity supply as well as upstream emissions. Moreover, the study discusses the concept of stranded investments and lock-in effects, particularly for low-carbon hydrogen production, providing insights into risks by investing into potentially short-lived low-carbon hydrogen plants. The results also underscore possible pathways to fully transition into renewable hydrogen exports with low-carbon hydrogen as a transitional means of hydrogen supply and the different

onset of ramping up low-carbon or renewable hydrogen production depending on our scenario analysis. The results thus show, that depending on the scenario, different factors such as CO2 pricing may have to be more ambitious than usually projected for the transition to initiate earlier and reach a natural gas phase out earlier than 2050. The results also show different impacts on total emissions and system costs under certain shares between low-carbon and renewable hydrogen. In cases such as Norway a forced early phase-out of blue hydrogen or allowance of green hydrogen only, results in higher system costs and high abatement costs per ton of CO2.

Conclusions

The transition from fossil fuels such as natural gas to low-carbon hydrogen, presents a viable pathway for Europe to decarbonize various sectors, with Norway poised to play a pivotal role as a key exporter of low-carbon hydrogen in the medium-term and Algeria of renewable hydrogen depending on the upstream emissions of low-carbon hydrogen production. In our study, we outline viable pathways for natural gas exporters like Norway and Algeria to transition their export focus from natural gas to hydrogen. However, it is clear that for this shift to occur, there must be compelling incentives in place. The transition to exporting low-carbon or renewable hydrogen hinges significantly on economic factors. Primarily, this involves higher CO2 prices and a sufficient development of cost degressions, ensuring that the supply costs arising from hydrogen exports compete against those from natural gas. This shift is crucial in making hydrogen a more attractive export option. Nonetheless, it is important to recognize that such a transition is also capital-intensive. Substantial investments are necessary to develop and establish a hydrogen export supply chain. This includes the infrastructure for production, storage, and transportation of hydrogen. The study underscores the need for a well-structured financial and policy framework to accelerate this ramp-up of hydrogen exports.

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