THE INDUSTRY TRANSFORMATION FROM FOSSIL FUELS TO HYDROGEN WILL REORGANIZE VALUE CHAINS: BIG PICTURE AND CASE STUDIES FOR GERMANY

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Overview

In many industries, low-carbon hydrogen will substitute fossil fuels in the course of the transformation to climate neutrality. This paper contributes to understanding this transformation. We provide an overview of energy- and emission-intensive industry sectors with great potential to defossilize their production processes with hydrogen. We asses future hydrogen demand for various defossilization strategies in Germany that rely on hydrogen as a feedstock or as an energy carrier to a different extent in the sectors steel, chemicals, cement, lime, glass, as well as pulp and paper. We find that aggregate industrial hydrogen demand in those industries would range between 197 TWh and 298 TWh if production did not relocate abroad for any sector. The range for hydrogen demand is mainly due to differences in the extent of hydrogen utilization as compared to alternative transformation paths for example based on electrification. We then asses the attractiveness of production abroad based on the prospective comparative cost advantage of relocating parts of the value chain to excellent production sites for low-carbon hydrogen. We provide case studies for the steel industry, as well as the chemical industry with ethylene production through methanol and the production of urea on the basis of ammonia. We compare the energy cost of the respective value chains in Germany to the case of value chains partly located in regions with excellent conditions for renewable energies and hydrogen production. Our results illustrate, that at least for some processes – as ammonia production – relocation to those favorable regions may occur due to substantial comparative cost advantages.

Methods

For the bottom-up calculation of the lower and upper limits of industrial hydrogen demand we carried out a literature review regarding the production outputs, capacities, emissions as well as fuel and energy consumption and demand for each relevant energy-intensive sector. After estimating a specific hydrogen consumption for each process, we come to conclusions by our literature review how each sector may utilize hydrogen and to what degree to constitute a lower and higher limit of demand. The lower limit constitutes a hydrogen utilization in sectors where it is exclusively necessary as a feedstock and for energetic use hydrogen will only play a supporting role. On the other hand, the upper limit constitutes, that hydrogen would play a more prominent role as a feedstock and for energetic use. For the analysis of the value chain costs we used a linear optimization model in the General Algebraic Modeling System (GAMS) environment. The objective was to minimize the sum of annual total cost of the whole supply chains for the production of steel, urea and ethylene through the intermediate products direct-reduced iron, ammonia and methanol. We compare 4 scenarios for each end product (steel, urea, ethylene). We compare the “Excellent site scenario” and the “Germany scenario” where each value chain and their respective intermediate products are only produced either in an excellent site with favorable renewable energy conditions and subsequent export of the end product to Germany or alternatively where the whole value chain remains in Germany. Another scenario in between sees the production of hydrogen in the excellent location and its transport to Germany, while the remaining value chain steps are carried out in Germany. The last scenario not only sees production of hydrogen in an excellent site but also the first intermediate product (iron, ammonia, methanol) while the last conversion step to steel, urea or methanol happens in Germany.

Results

In our bottom-up analysis for industrial hydrogen demand in Germany we show, that the demand for a climate-neutral industry would amount to between 197 TWh and 298 TWh which would be a great increase from the 55 TWh hydrogen consumed in Germany today. This is largely thanks to the increased use of hydrogen as a feedstock in the steel industry and the chemical industry, especially for methanol and ammonia production. The large increase in hydrogen demand for methanol production is also thanks to the future production of organic chemicals by methanol instead of naphtha from crude oil as it is currently. The highest hydrogen demand for energetic (heating) use only amounts to 57 TWh mainly in the cement, lime, glass and paper industry.
For the value chain costs we show that especially the production of ethylene and urea through methanol and ammonia respectively have large cost differences between a complete production abroad versus the total value chain remaining Germany. Reason is largely because of their large dependency on hydrogen and thus renewable energy which are much cheaper in favorable regions with good PV and wind conditions. For the production of steel, the difference is rather marginal because the transformation of the steel industry to sustainable production is more capital cost intensive than dependent on renewable energies and hydrogen.

Conclusions

The climate-neutral transformation of German industry requires fundamental changes in production processes and thus also in the feedstocks to be used. Alongside electricity from renewable sources, low-carbon hydrogen will be an important component of a sustainable industry. Ultimately, the actual hydrogen demand for each sector will depend on whether the respective companies decide to run their climate-neutral production in Germany or relocate (parts of) the value chain abroad due to cost advantages. In addition to comparative costs, however, the availability of hydrogen and hydrogen transport infrastructure in Germany will play a key role in decision-making. Even if sufficient production of hydrogen in Europe at competitive prices is not possible in the long term, a timely ramp-up of production may be appropriate. Policymakers must be aware that decisions on investments in new carbon-neutral production processes will have to be made very soon in order to meet climate targets. The more uncertain access to hydrogen at competitive prices is in Germany and Europe, the more likely it is that large-scale value creation will be shifted abroad.