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A meta-study

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Imports of green hydrogen and its derivates to Germany in a climate neutral future A meta study

David Ruprecht[1*], Tapio Schmidt-Achert[1], Jakob Zahler[1], Simon Pichlmaier[1]

In recent years, several major studies were published describing pathways to an energy system for a climate neutral German economy as well as the future demand of green hydrogen and potential subsequent products in these pathways. Consequently, the question arises how to manage the supply of hydrogen. The amount of the imports of hydrogen and its derivates are given in most of these studies, leading to information about anticipated import shares of these important energy carriers.

This paper analyzes imports of hydrogen in five scenarios from four major German energy system studies. The focus is set on the absolute amounts of imported hydrogen and the share of imports in the total energy demand. While there is broad consensus that most of Germany's future hydrogen derivates demand will be imported, relevant differences between the absolute and relative amount of green hydrogen imports can be identified. The share of imports can provide an indication on Germany's future dependency on energy exporting countries.

Finally, a comparison to global hydrogen scenarios is taken to analyze global hydrogen trade flows, which indicate that Europe – other than the United States of America - will be a major importer of hydrogen.

Introduction

The latest geopolitical events have shown Germany's current dependency on fossil energy carriers and the countries exporting them. To reach its goal of becoming climate neutral by 2045, Germany needs to expand its energy generation from renewable sources massively. Nevertheless, due to limited renewable energy potentials, there will still be a need to import energy in form of green hydrogen produced by electrolysis and green hydrogen derivates such as Ammonia or Methanol. Since these synthetic energy carriers will play an important role in the future, their import shares in Germany and therefore Germany's future dependency on exporting countries are of particular interest.

Methodology

This paper analyzes the imports of hydrogen and hydrogen derivates to Germany and their overall demand from four recent major German energy system studies that analyze pathways towards climate neutrality in 2045. While the focus is set on the target year 2045, the situation in the transition year 2030 is also examined. Three of the investigated studies and their scenarios (*Agora KNDE2045*, *BDI 2.0* and *dena KN100*) were published in 2021 while one study containing the two scenarios *LFS T45-Strom* and *LFS T45-H2* was published in November 2022. The *Ariadne-Report* [1], which is also considered a major German energy system study,

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is not evaluated due to difficulties of determining the imports of hydrogen derivates and a wide variety of scenarios and models in this study.

Additionally, recent studies for international hydrogen trade are analysed to compare results between German and international studies and identify possible export countries. These studies assess possible future international hydrogen trade volumes and routes. *IRENA* [2] and *AFRY* [3] both use cost optimization transport models to evaluate possible international future hydrogen trade volumes. IRENA additionally assesses the impact of parameter variations in different scenarios. Due to incomplete data availability, only the main *optimistic* scenario is considered in further analysis.

Imports 2030

Since the newest scenarios from *Langfristszenarien (LFS)* do not yet provide data considering the use and import of hydrogen derivates (PtG/PtL for Power-to-Gas/Power-to-Liquid) in 2030 [4], data can only be given for the remaining three scenarios. The total amounts of imported synthetic energy carriers are ranging from 45 to 59 TWh [5–8]. The differences in the total demands of synthetic energy carriers in 2030, ranging from 64 to 99 TWh, result from a wide range of their domestic production [5–8]. Therefore, also the import shares vary from 55 % in *BDI 2.0* [5] to 86 % in *dena KN100* [6] as can be seen in Figure 1.

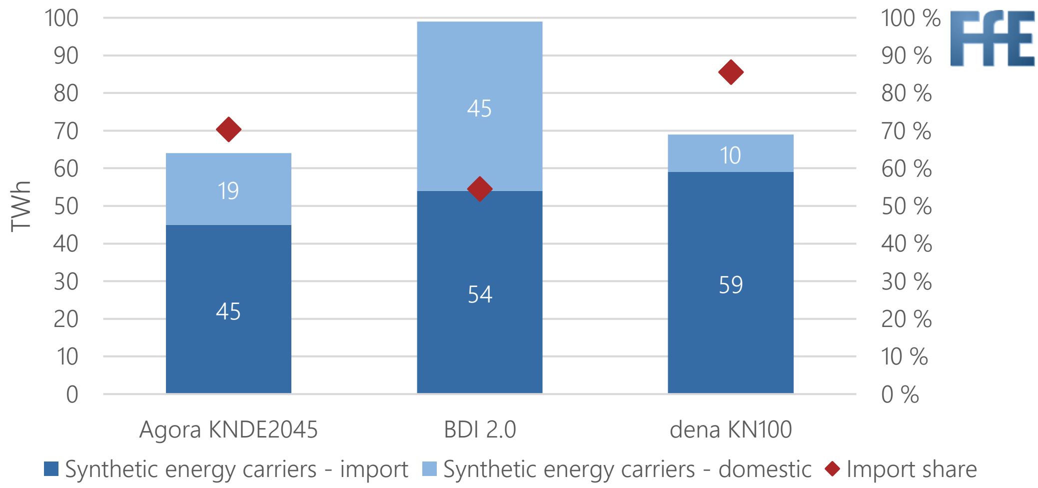

Figure 1: Imports and domestic production of synthetic energy carriers 2030 [5–8]

The average import share of all synthetic energy carriers for these three scenarios is 68 %, with 58 % of green hydrogen and close to all derivates being imported in 2030 [5–8].

Imports 2045

Reaching the goal of becoming climate neutral by 2045, the imports and the overall demand of synthetic energy carriers rises substantially in comparison to 2030. This results in an import range starting from 324 TWh in *Agora KNDE2045* [7] and ending with 615 TWh in *LFS T45-H2* [4] (see Figure 2). Overall demand ranges from 420 to 887 TWh, with substantial differences in domestic production potentials [4–8].

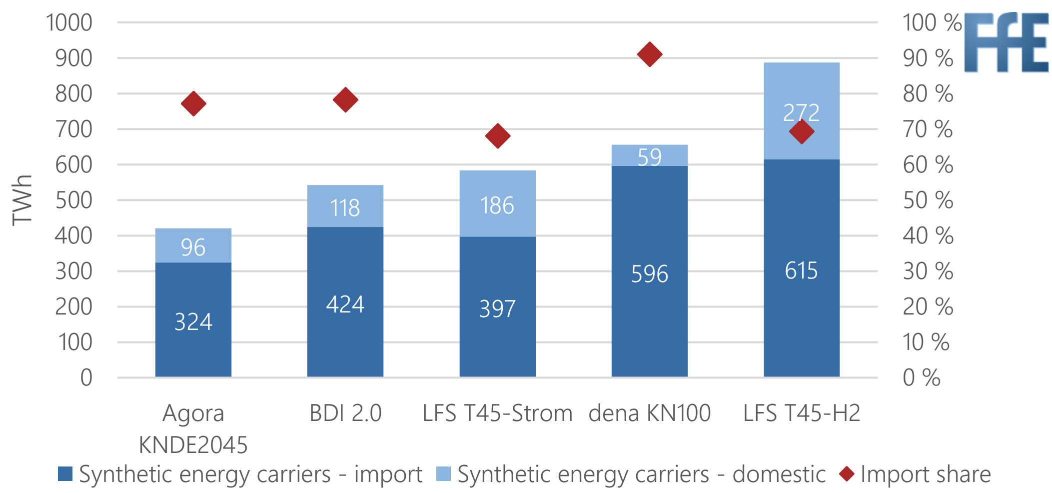

Figure 2: Imports and domestic production of synthetic energy carriers 2045 [4–8]

These differences in domestic production potentials between the scenarios also lead to differences in the import shares of the synthetic energy carriers, as can also be seen in Figure 3. Therefore in *dena KN100*, accounting for the lowest domestic production, the highest import share of 91 % can be identified [6]. With 77 % and 78 % *Agora KNDE2045* and *BDI 2.0* show very similar import shares [5, 7]. While in the 2021 version of the *Langfristszenarien* the import shares were situated at around 80 % as well [9], the 2022 version accounts for lower shares of 68 % and 69 % [4]. This can primarily be attributed to an increased domestic hydrogen production.

Regarding PtG/PtL there is broad consensus in all studies that these energy carriers will exclusively be imported, with just a marginal amount being produced domestically in *BDI 2.0* [4–8]. Partly these studies are taking exogenous assumptions that all PtL is going to be imported. Looking at green hydrogen a wide range of the share of imports was identified, reaching from 49 % to 87 % [4–8].

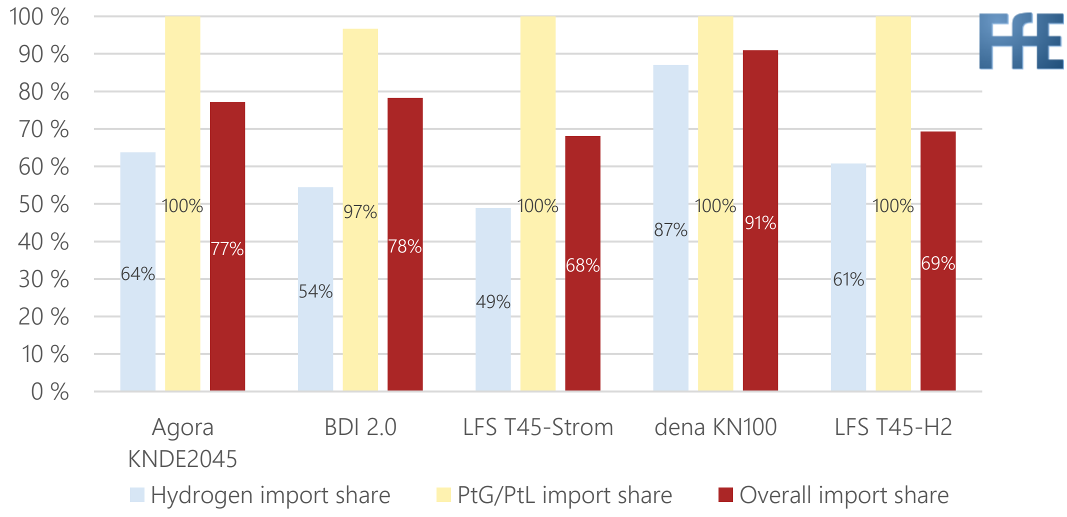

Figure 3: Import shares of hydrogen and its derivates in 2045 [4–8]

Taking a closer look at the imported synthetic energy carriers, the amounts of PtG/PtL imports are assessed more similarly throughout the studies and scenarios than those of green hydrogen (see Figure 4). PtG/PtL imports range from 155 to 295 TWh in 2045, while the range for green hydrogen is substantially wider starting from 129 TWh in *BDI 2.0* and ending at 422 TWh in *LFS T45-H2* [4–8].

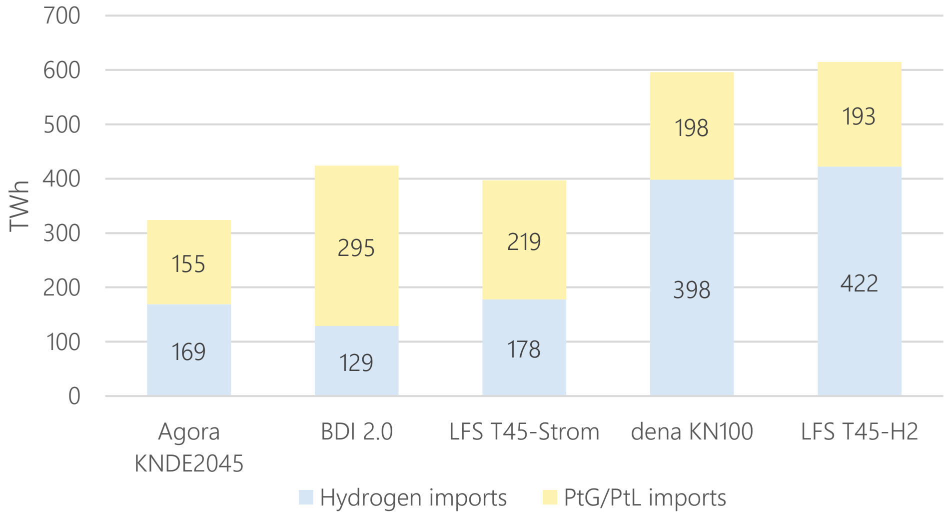

Figure 4: Imports of green hydrogen and PtG/PtL in 2045 [4–8]

International perspective

The *AFRY Global Hydrogen Trade Model* [3] assesses possible future hydrogen trade volumes internationally and shows a total import of 390 TWh of hydrogen to Germany in 2050, showing values at a similar range as German studies shown in Figure 4. Most hydrogen is delivered from Northern Africa through Italy. The remaining hydrogen is being delivered from Norway (no exact values given). Numbers for the local production or total demand of hydrogen are not available, which does not allow to quantify import shares.

The *IRENA* [2] model distinguishes between ammonia and hydrogen flows. According to the *IRENA* model Germany satisfies 70 % of its hydrogen demand in 2050 from imports and furthermore imports all its ammonia, which is in accordance with the shares in German energy system studies shown in Figure 3. Hydrogen demand in Germany is seen at 340 TWh and demand for ammonia at 106 TWh in 2050. For Europe most imports are seen from North Africa with 661 TWh of hydrogen and 446 TWh of ammonia imported to Europe. 1308 TWh of hydrogen are produced in Europe locally, additional ammonia is imported from Latin America, and the Middle East at lower extent, with no exact values given. Important trading and transit hubs are therefore Italy and Spain.

In the global perspective Germany together with the rest of Europe, Japan and the Republic of Korea will be one of the biggest importers of hydrogen in the world according to *IRENA [2]*. The biggest exporters identified in the study are North Africa, Australia, and Chile. In contrast, the United States and China, the two largest demand regions for hydrogen, will be close to self-sufficient. The United States even show a potential for ammonia export.

Development of the shares of energy imports in the total energy demand

As described before, substantial amounts of energy in form of synthetic energy carriers, ranging from 324 to 615 TWh [4–8], will be imported by 2045 to Germany, as can be seen in

Figure 5. Nevertheless, comparing these numbers with the current imports of fossil energy carriers, i.e. coal, oil and gas, energy imports to Germany would be drastically reduced by 72 to 85 % compared to more than 2200 TWh of fossil imports in 2021 [10].

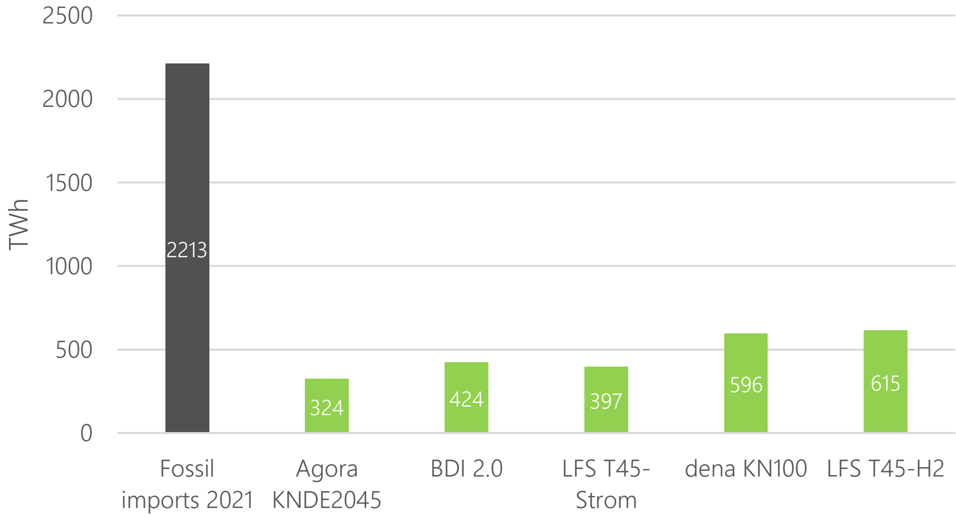

Figure 5: Imports of fossil energy carriers in 2021 and imports of synthetic energy carriers in 2045 to Germany [4–8, 10]

Not only the overall amount of energy imports will decrease, but also the share of these energy imports in the total energy demand as shown in Figure 6. While the share of fossil imports in the primary energy consumption in 2021 was at 64 % [10], synthetic imports will only make up for an average of 25 % of the primary energy consumption in 2045 with shares ranging from 18 % to 33 % for different scenarios[2] [5–8]. The decrease in relative numbers shown in Figure 6 is lower compared to the reduction in absolute imports shown in Figure 5, since the total primary energy demand will significantly decrease in all scenarios. This reduction of primary energy demand mainly results from direct electrification and high shares of electricity demand supplied by local renewable energy. In summary, the dependency of Germany on energy exporting countries would be significantly reduced in comparison to today's situation.

[2] No primary energy consumption data available for *LFS T45* scenarios

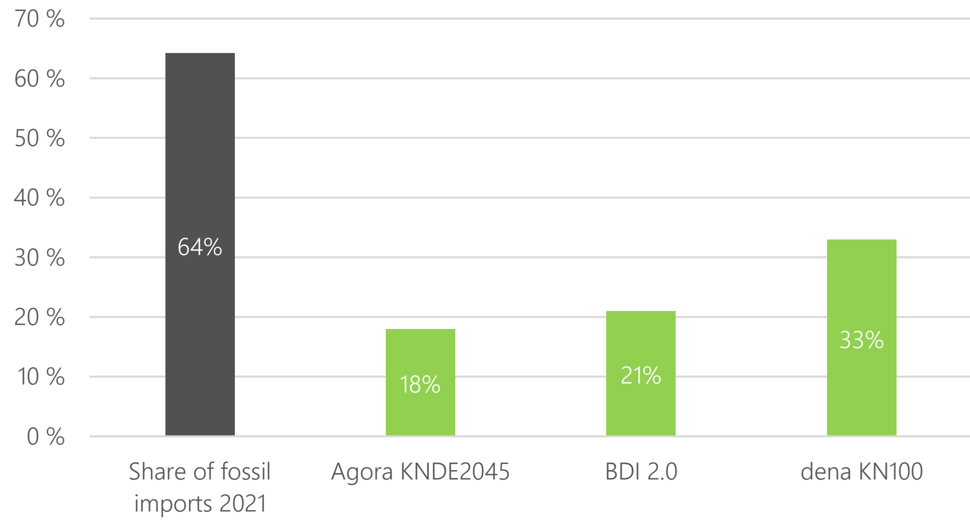

Figure 6: Share of fossil imports 2021 and imports 2045 in the primary energy consumption [5–8, 10]

Conclusion

Germany will stay an energy importing country, but German import dependency in future climate neutral scenarios would be significantly reduced in absolute and relative numbers. Fossil imports of 2213 TWh in 2021 would reduce to imports of synthetic energy carriers between 324 TWh and 615 TWh in 2045 depending on the scenario. The share of imports in the primary energy consumption will also significantly decrease from 64 % in 2021 to 18 % to 33 % in 2045.

Hydrogen and its derivatives will be imported to a large extent. Hydrogen imports to Germany in 2045 range from 129 TWh to 422 TWh across studies and import shares range from 49 % to 87 %. For derivates imports range from 155 TWh to 295 TWh, which accounts for most of the consumption. Similar magnitudes of imports result from both the German and international studies analyzed.

International hydrogen trade models see Germany as one of the major importers. North Africa and European countries like Norway are seen as main suppliers. In contrast, the largest hydrogen demand regions China and the United States will be largely self-sufficient.

Acknowledgments

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