Institute of Energy Economics
at the University of Cologne

[EWI Analysis]

Supply Security of Green Hydrogen and Ammonia Imports to Germany

Assessing export countries' supply costs and EWI Future Energy Score

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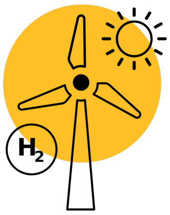

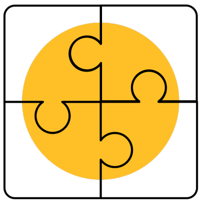

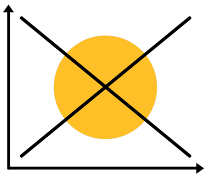

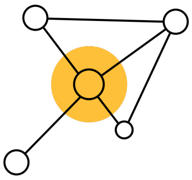

Institute of Energy Economics
at the University of Cologne

Institute of Energy Economics at the University of Cologne gGmbH (EWI)

Alte Wagenfabrik
Vogelsanger Straße 321a
50827 Cologne/ Germany

Tel.: +49 (0)221 650 853-60
https://www.ewi.uni-koeln.de

Authors
Dr.-Ing. Ann-Kathrin Klaas
Nada Fadl
Carina Schmidt

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Contents

1 The role of green hydrogen imports in Germany

Germany has been heavily reliant on imports of fossil fuels, as domestic resources are very limited, thus exposing itself to considerable supply and price risks. While the transition towards renewable energy sources (RES) aims at achieving Germany's climate target of net-zero emissions by 2045, it is poised to affect the risks associated with energy supply and import dependence as well.

Reaching Germany's climate targets may require annually 150 to 600 TWh of green hydrogen as well as 100 to more than 400 TWh of green derivatives, much of which are likely to be in the form of ammonia (EWI & BET, 2025). Given the limitations of domestic RES potentials, relying solely on national production may be insufficient, as well as cost-inefficient. Hence, imports of green hydrogen and its derivatives are likely to play an important role in meeting these targets (EWI & BET, 2025), which is also reflected in Germany's system development strategy, where a hydrogen import share of 50-70 percent in 2045 is targeted (BMWK, 2024).

From the perspective of security of supply, early-on diversification of supply countries constitutes a key strategic consideration. Compared to fossil fuels, there are many more potential exporters of green commodities. In theory, every country worldwide has some RES potential and, thus, could potentially produce green hydrogen and derivatives. In practice, though, not all countries will develop hydrogen production and out of these that do, some will have strong comparative advantages supplying Germany. While supply costs are decisive for the economic efficiency of green fuel imports, other preconditions such as political and economic stability and existing infrastructure and expertise may prove decisive for the security of supply.

In this study, we evaluate potential supply conditions for green hydrogen and ammonia, analyzing both supply costs and the political, social and economic preconditions of individual countries. The methodology is based on the EWI Global PtX Cost Tool and the EWI Future Energy Score. This analysis updates the EWI Future Energy Score (EFES) (EWI, 2023) with new data and combines the EFES with supply costs for green hydrogen and ammonia from the newest version of the EWI Global PtX Cost Tool V2.1 (EWI, 2025).

The analysis is conducted separately for green hydrogen and green ammonia. While both commodities have similar requirements concerning socio-economic conditions (which we capture in the EFES), supply costs may differ significantly. Maritime imports of hydrogen entail a significant cost component for conversion processes, since hydrogen cannot be shipped economically in gaseous form and it has to be liquefied first. For instance, for some countries transport cost for liquefied hydrogen can constitute more than 30% of the total supply cost. As a result, the hydrogen trade is likely to be cost-efficient only for countries connected via a hydrogen pipeline to Germany. Ammonia and other hydrogen derivatives have much higher energy density and may be used directly for the provision of process heat or as a feedstock for the chemical industry, avoiding additional costs for the reconversion to hydrogen. Thus, they offer lower transportation costs at greater distances making production in other regions of the world economically more viable in comparison to hydrogen import but also in comparison to domestic ammonia production.

Securing strategic partners, both within the EU and outside it, may prove essential for Germany's hydrogen import strategy as future hydrogen supply will depend on reliable external sources and stable long-term cooperation. This analysis examines the conditions for green hydrogen and ammonia imports, focusing on countries with existing hydrogen partnerships with Germany. Figure 1 shows the countries included in the analysis: Australia (AU), Brazil (BR), Canada (CA), Chile (CL), Egypt (EG), Finland (FI), Mexico (MX), Morocco (MA), Namibia (NA), Spain (ES), and Turkey (TR). These countries were selected due to their existing hydrogen partnership with Germany and to reflect a globally diversified portfolio of potential hydrogen and ammonia export countries.

A brief description of the methodological approach is given in Chapter 2, while chapter 3 presents the results and discusses these. Chapter 4 concludes.

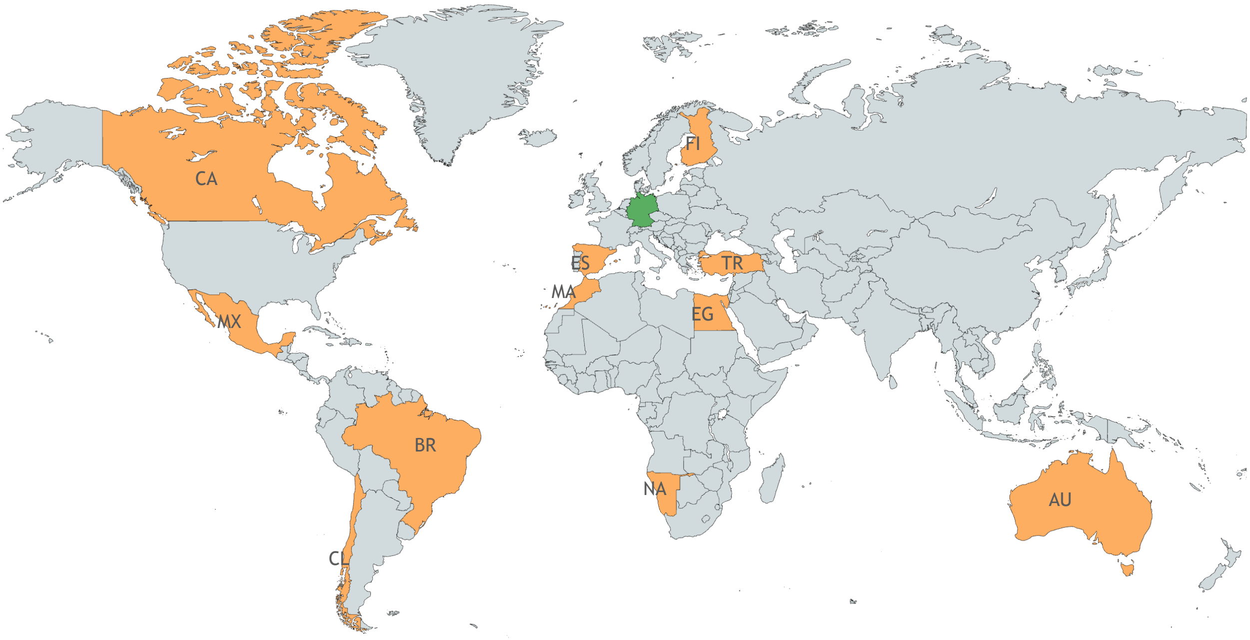

Figure 1: Countries with hydrogen or energy partnerships with Germany that are included in the analysis.

2 Supply costs and country-level performance score

This chapter describes the approach to analyzing the supply conditions for green hydrogen and ammonia. Supply costs are evaluated based on the EWI Global PtX Cost Tool V2.1 (EWI, 2025). The country-level performance regarding security of supply is reflected in and evaluated with an updated version of the EWI Future Energy Score (EWI, 2023).

2.1 Green hydrogen supply costs and potentials

The *EWI Global PtX Cost Tool V2.1* provides cost estimates for the global supply of green hydrogen and hydrogen derivatives (ammonia, methane, methanol and Fischer-Tropsch fuels) from wind and solar energy. It allows the user to retrieve supply costs and production potentials, assuming a stand-alone, fully integrated green commodity plant including a dedicated RES power plant located at the site and conversion plants like electrolysis and ammonia synthesis. As the production costs exhibit scale effects, the calculations assume a supply volume of 100 TWh. The Tool covers 117 origin countries, while calculating transport costs to 22 destination countries. Supply costs are defined as the sum of production costs and transport costs.

Figure 2 shows costs of green hydrogen imports to Germany in 2030 as an example of the scope and the results of the tool.

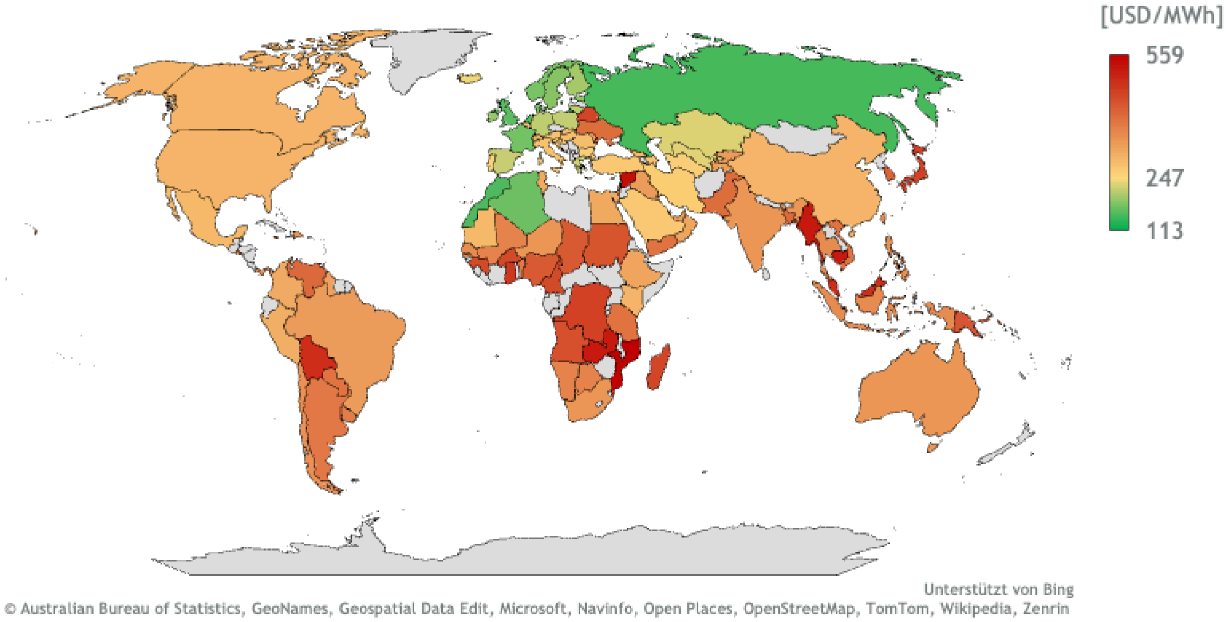

Figure 2: Green hydrogen import cost to Germany for 2030 (Baseline scenario, weighted average for the supply of 100 TWh/a, cheapest transport method). *Source: EWI Global PtX Cost Tool V2.1 (EWI, 2025)*

The RES considered in the model include photovoltaic (PV), onshore wind, and offshore wind. Country-specific RES input parameters comprise hourly capacity factor profiles as well as the respective technical potentials. In addition, country-specific economic parameters are incorporated, including the Weighted Average Cost of Capital (WACC), labor costs, and investment costs. Figure 3 presents a cost breakdown of hydrogen supply costs by RES class for the case of hydrogen production occurring in Germany.

In this analysis, supply costs include production costs in the origin country and transport costs to Germany. Transport costs only reflect cross-country transport and are therefore equal to zero for domestic production. The RES classes are differentiated by capacity factor for PV and onshore wind, and by water depth for offshore wind. The bars correspond to the left y-axis and indicate the supply costs associated with each RES class. The right y-axis shows the corresponding production potential of each class, represented by diamond markers. The weighted average cost represents the aggregated cost of the least-cost RES classes required to meet a predefined annual supply volume of 100 TWh. Supply potentials in the EWI PtX Cost Tool are technical potentials, and do not account for the competition for RES in direct use of electricity as well as infrastructure and ramp-up constraints.

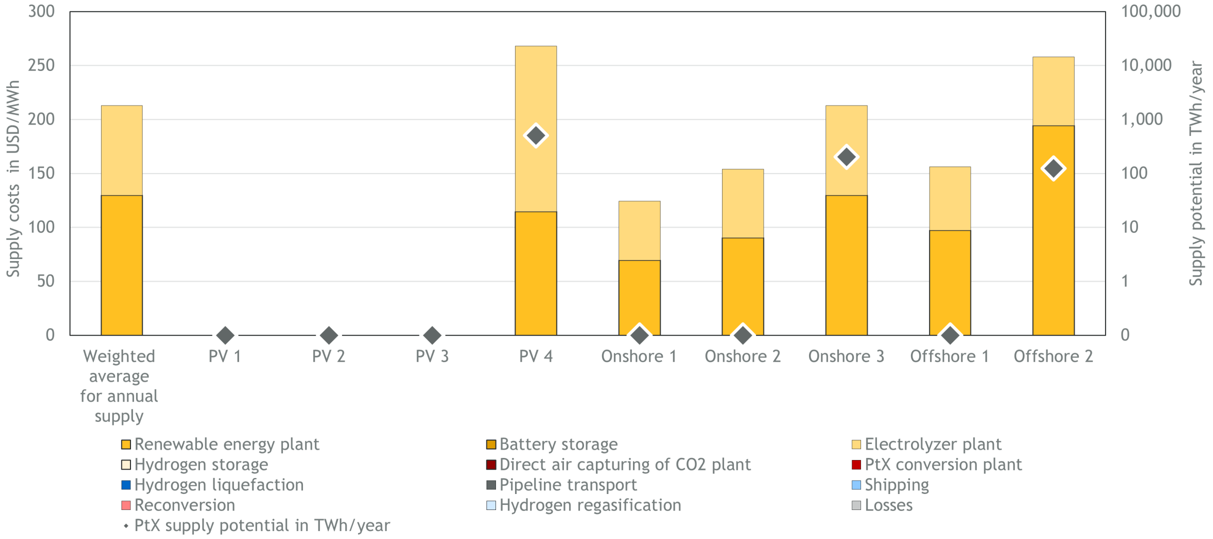

Figure 3: Domestic production green hydrogen supply costs in Germany for 2030 (Baseline scenario). *Source: EWI Global PtX Cost Tool V2.1 (EWI, 2025)*

For 2030, the estimated costs for supplying green hydrogen to Germany vary between approx. 213 USD/MWh and over 267 USD/MWh[1], as shown in Figure 2. The lowest weighted average costs occur when importing from European countries such as Norway (176 USD/MWh), the UK (161 USD/MWh), the Netherlands (155 USD/MWh) or Morocco (156 USD/MWh). Hydrogen production in Germany exhibits a similar cost level with 213 USD/MWh. Countries without the possibility of a pipeline connection show higher supply costs, starting at approx. 250 USD/MWh given that energy demand and losses during conversion and reconversion for shipping result in significantly higher transport costs compared to the transport via pipeline. Among the countries without the

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[1] This is according to the baseline scenario in the EWI Global PtX Cost Tool V2.1 (EWI, 2025), which affects the investment cost projection of all components of the production systems in the origin countries. In the optimistic scenario, the investment cost decreases more strongly over time due to higher scale effects and learning.

pipeline option, Saudi Arabia and Mexico are the most cost-efficient due to their low production costs.

Supply costs for green ammonia are estimated to start at approximately 165 USD/MWh in 2030[2]. Compared to pipeline transport, maritime shipping of ammonia may offer cost advantages due to its higher volumetric energy density. Countries such as Morocco (183 USD/MWh) and Algeria (200 USD/MWh) exhibit the lowest supply costs, reflecting favorable renewable resource conditions and production potentials. By contrast, domestic production costs in Germany are high, reaching around 326 USD/MWh.

Production costs vary significantly depending on the underlying renewable energy technology and its associated capacity factor. The values reported above represent weighted averages of the most cost-efficient renewable energy potentials. Consequently, these estimates can be interpreted as a lower-bound approximation of supply costs. For the subsequent comparison in section 3, individual RES classes and their corresponding supply costs are therefore evaluated separately.

2.2 Country-level supply performance score

The EWI Future Energy Score (EFES) complements a cost-based analysis by enabling cross-country comparison of exporting preconditions beyond cost factors. Each country is assigned a score ranging from 0 to 100. The EFES takes into account factors that may endanger the reliability of future energy supply, potentially hindering or threatening the export of green commodities.

The score is based on four sub-indicators: economic (ECO), energy (EN), political (POL), and social (SOC) indicators. The four indicators are combined to assess the overall country performance. A higher score can be interpreted as better conditions in terms of security of supply for hydrogen imports from the respective country. The EFES is based on a principal component analysis (PCA), where all four sub-indicators are equally weighted.

Input data for EFES consist of various variables such as the gross domestic product (GDP) and inflation, global peace and civil rights index, energy use and shares of RES, population growth and access to electricity. Figure 4 shows an overview of the approach and the variables which construct each sub-indicator. The original EFES (EWI, 2023) was updated to cover the years 2022 to 2024.

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[2] This is according to the baseline scenario in the EWI Global PtX Cost Tool V2.1 (EWI, 2025).

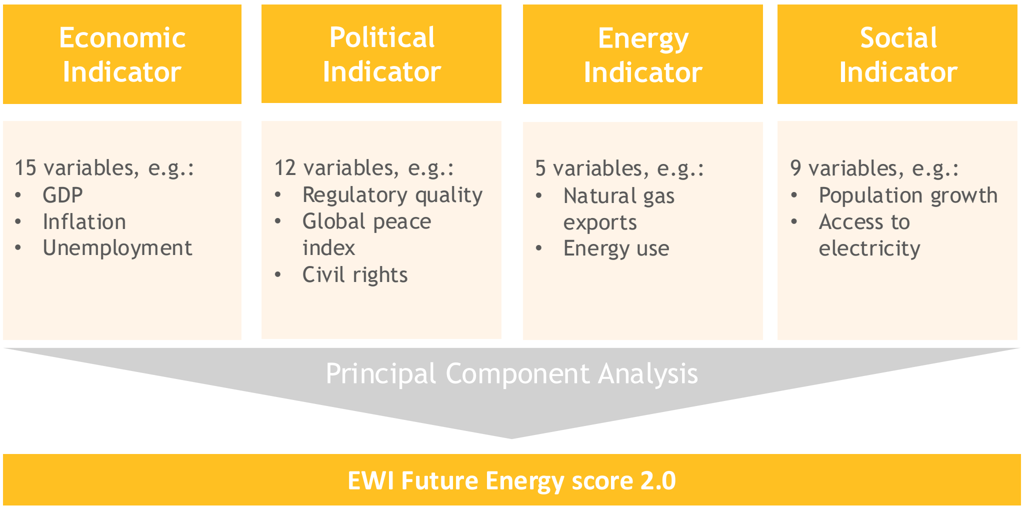

Figure 4: Approach of the EWI Future Energy Score 2.0

Why PCA is used The approach relies on a multivariate analysis, which improves the results by accounting for the relationships among the random variables. A commonly employed technique in this context is PCA. The PCA method is a data analysis technique which linearly transforms a set of correlated variables under certain conditions (Jackson, 1991; Jolliffe, 2002, 2022). It is used to construct a score or an index. This is done by reducing the dataset's dimensionality while preserving as much information as possible. This method is particularly useful when handling a large number of potentially correlated variables.

Since no single variable can fully capture a country's performance across economic, energy, political, and social dimensions, using a set of variables together provides a more comprehensive reflection of overall country performance. This is why PCA is a particularly suitable approach, as it can combine multiple correlated variables into a single index or score while retaining the maximum amount of information.

Steps of the PCA procedure For the evaluation of the EFES, we collect the relevant variables associated with each sub-indicator and perform data pre-processing, such as standardization or normalization. The correlation matrix is computed to examine the relationships between the variables. The eigenvalues and eigenvectors of the correlation matrix are determined, where each eigenvalue indicates the amount of variance explained by its corresponding eigenvector.

The next step involves selecting the eigenvalues that account for the majority of the variance, with their associated eigenvectors representing the principal components that capture the most significant patterns in the data. Then the component scores by projecting the original standardized data onto the chosen principal components. Finally, the component scores are aggregated to construct the sub-indicators and the overall EFES. To test for sample adequacy by examining the correlations and partial correlations between the variables, we employ the Kaiser-Meyer-Olkin (KMO) test as demonstrated in Table 1.

Indicator	Final number of variables	Kaiser-Meyer-Olkin (KMO)	Total variance %
Economic	15	0.7	70
Political	12	0.9	76
Social	9	0.7	78
Energy	5	0.65	72

Table 1: Variable selection

Figure 5 shows the resulting EFES for the selected countries of this analysis including Germany for comparison. The EFES of the evaluated countries ranges between 37 and 60. Canada and Australia show the highest EFES, mainly due to their comparably high political and energy sub-indicators. Germany follows Canada and Australia, exhibiting the highest score for the Economic sub-indicator among the evaluated countries. A high EFES often aligns with a high political subindicator, as this indicator shows the highest spread. The economic and social subindicators range between 30 and 60 for all countries, while the energy indicator exhibits values below 20 for some of the selected countries.

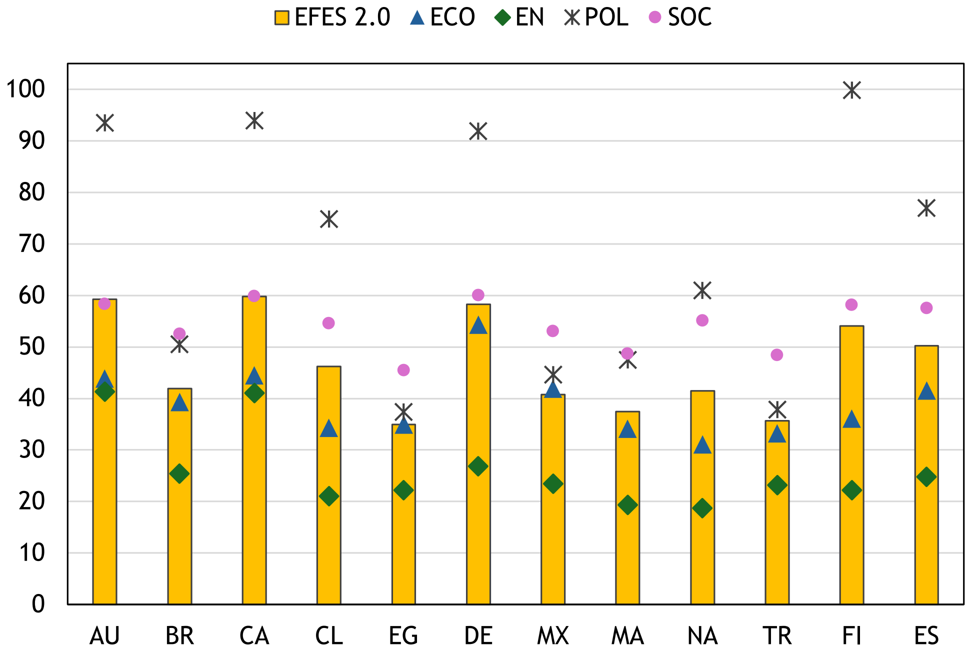

Figure 5: Results of the EWI Future Energy score 2.0 (EFES 2.0) based on the years 2022 to 2024 for selected countries.

A high political subindicator may represent stable political conditions. As an example, Finland reaches the highest possible score in the political sub-indicator. However, the energy subindicator of Finland is rather low, as for example natural gas infrastructure is scarce. This may indicate that Finland has less experience with the production, consumption or export of energy commodities. More information on the EFES can be found in EWI (2023).

3 Efficiency clusters: Considering supply costs and the performance score

Having separately examined the supply costs and the performance score in Chapter 2, this analysis now integrates these two parameters to enable a comprehensive assessment of the export potential of individual countries. The results are presented as an efficiency cluster map, which combines the EFES and the hydrogen (or ammonia) supply costs with the technical production potentials for hydrogen (or ammonia).

The map assigns countries to four clusters. Countries characterized by a low EFES (< 48) and high supply costs (> 300 USD/MWh) are categorized as belonging to the “inefficient” cluster. In contrast, countries with a low EFES but comparatively low supply costs are assigned to the “cost-efficient” cluster. Countries with a high EFES (> 48) but high supply costs (> 300 USD/MWh) fall into the “score-efficient” cluster, whereas countries that combine a high EFES with low supply costs are classified as “efficient.” The threshold values of EFES = 48 and supply costs = 300 USD/MWh serve as indicative reference points rather than strict cut-off criteria. It should also be noted that supply costs vary across different RES classes. Therefore, there are multiple points for each country and some countries may appear in more than one cluster.

3.1 Efficiency clusters for green hydrogen

Green hydrogen supply costs and technical potentials are compared to the country-specific EFES in an efficiency cluster map in Figure 6. The x-axis shows the EFES 2.0 of the origin countries. The y-axis displays the supply costs of green hydrogen to Germany. The bubble size represents the technical potential, which is the maximum annual quantity in TWh/yr which can be produced at the given cost, while accounting for technical limitations.

Efficient cluster Finland and Spain exhibit the lowest supply costs combined with the most favorable score, with performance scores for Finland, and Spain of 54, and 50, respectively. Furthermore, Finland and Spain have the advantage of coherent business and investment environments due to the single EU market and a single currency. The countries’ hydrogen import costs start at 200 USD/MWh. Especially Spain offers a high production potential at low costs due to its large and efficient solar potentials (EWI, 2025). The short distance to Germany makes pipeline exports economically viable for both Finland and Spain. Furthermore, the onshore wind based hydrogen production potential in Canada is on the threshold of the efficient cluster. Additionally, Canada shows the highest EFES of all analyzed countries. The political and social indicators exhibited by the three countries indicate a high level of political and social stability.

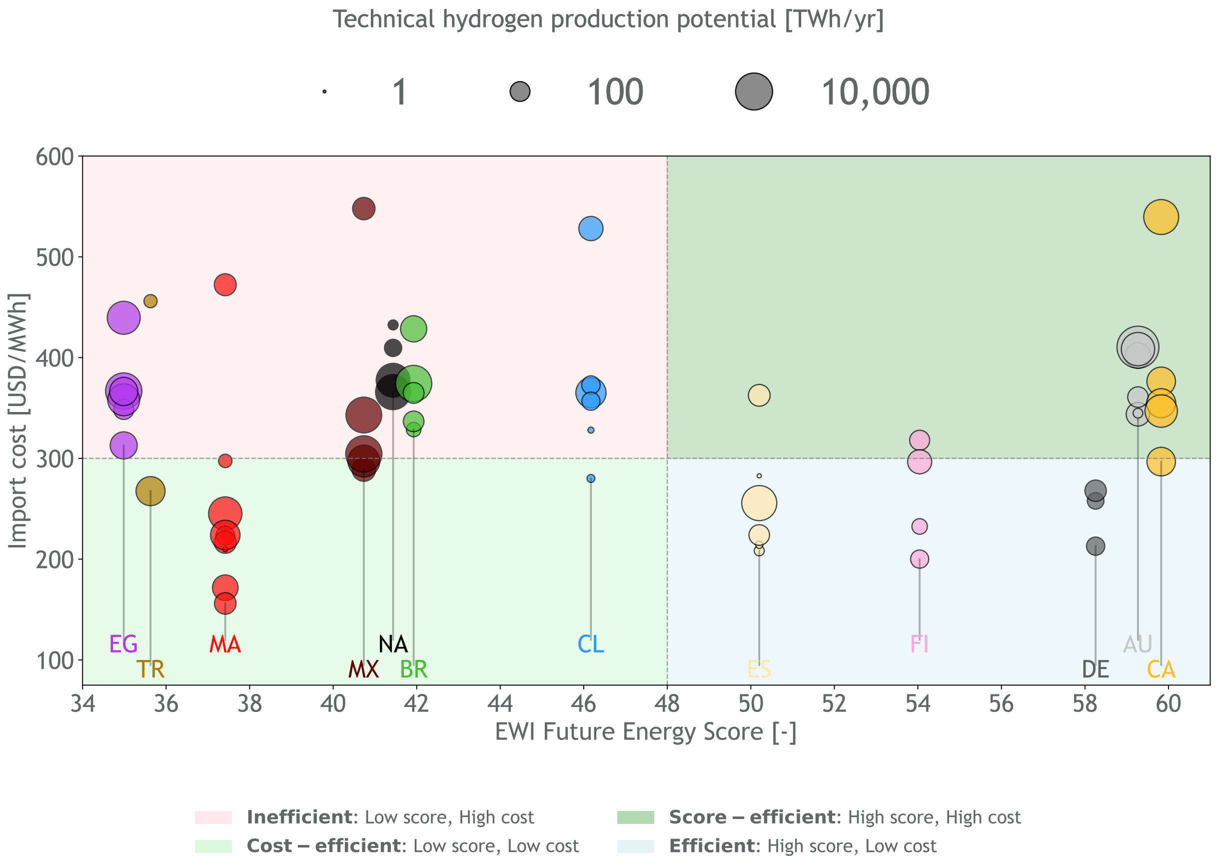

Figure 6: Efficiency cluster map displaying supply costs, score performance and technical potentials for green hydrogen

Notably, Germany is part of the efficient cluster, suggesting that self-supply would be efficient. However, limited domestic supply potential based on RES potentials constrains hydrogen production in Germany significantly.

Score-efficient cluster Countries in this cluster include foremost Australia and Canada and are characterized by a high EFES and high supply costs. Finland and Spain also offer some hydrogen production potentials in this cluster, but most of their potentials are located in the efficient cluster. Australia and Canada have a performance score of 59 and 60, respectively, both showing high economic and energy sub-indicators. While both countries' performance scores are the most favorable among the countries evaluated in this analysis, their hydrogen supply costs are significantly higher than of those countries in the efficient cluster, ranging between approx. 330 and over 500 USD/MWh.

Cost-efficient cluster Mexico, Morocco, and Turkey exhibit the low costs with a less favorable country performance compared to the efficient cluster. The performance score for Morocco, Mexico, and Turkey is 37, 41, and 36, respectively. Importantly, Morocco offers a high technical supply potential due to its solar RES potentials (about 60% of the total supply potential in the cost-efficient cluster) at the lowest cost among the countries evaluated (156 USD/MWh). While this advantage comes with a trade-off in its country-level performance score, the country could be a significant supplier especially in the later stages of the market ramp-up when high quantities are demanded. Mexico has a higher performance score than Morocco, but in turn exhibits higher supply costs on the threshold to the inefficient cluster. Higher costs are mostly due to the distance and the need for maritime transport, which is significantly more expensive than pipeline transport. Turkey offers slightly lower supply costs than Mexico (around 280 USD/MWh), but also exhibits the second to lowest performance score of all analyzed countries. Although both Morocco and Turkey are further from Germany than those countries in the efficient cluster, they remain within feasible pipeline-based transport distance. Higher transport costs are compensated by substantially lower hydrogen production costs, driven by abundant RES with high potential. Additionally, Mexico appears as a new potential supplier which has previously not been discussed much due to geographical distance.

Inefficient cluster Countries exhibiting a less favorable score (<48) and high supply costs (> 300 USD/MWh) belong to the inefficient cluster. These are foremost Egypt, Namibia, Brazil and Chile of those countries analyzed in this study. Comparably high supply risks and costs restrict these countries' ability to compete with more efficient and cost-effective suppliers. However, countries in the inefficient cluster exhibit the highest technical production potential for green hydrogen of all analyzed countries. Targeted investments, technological upgrading and policy reforms may lower supply costs and/or improve the performance scores in order to unlock the supply potential.

3.2 Efficiency clusters for green ammonia

Figure 7 shows the efficiency cluster map for green ammonia, which displays costs, score performance and technical production potentials in the respective countries. The underlying definition for the clusters is the same as for the green hydrogen efficiency cluster map.

Efficient cluster Australia, Canada, Finland and Spain are on the threshold of the efficient cluster for green ammonia, offering low supply costs and favorable performance scores. However, compared to the potential for green hydrogen, the technical potential of these countries in the efficient cluster is significantly smaller, and most of their green ammonia production potentials can be found in the score-efficient cluster with higher costs. The lowest supply costs in the efficient cluster can be found in Finland at around 280 USD/MWh, but the majority of the supply potential in this cluster is located in Australia and Canada.

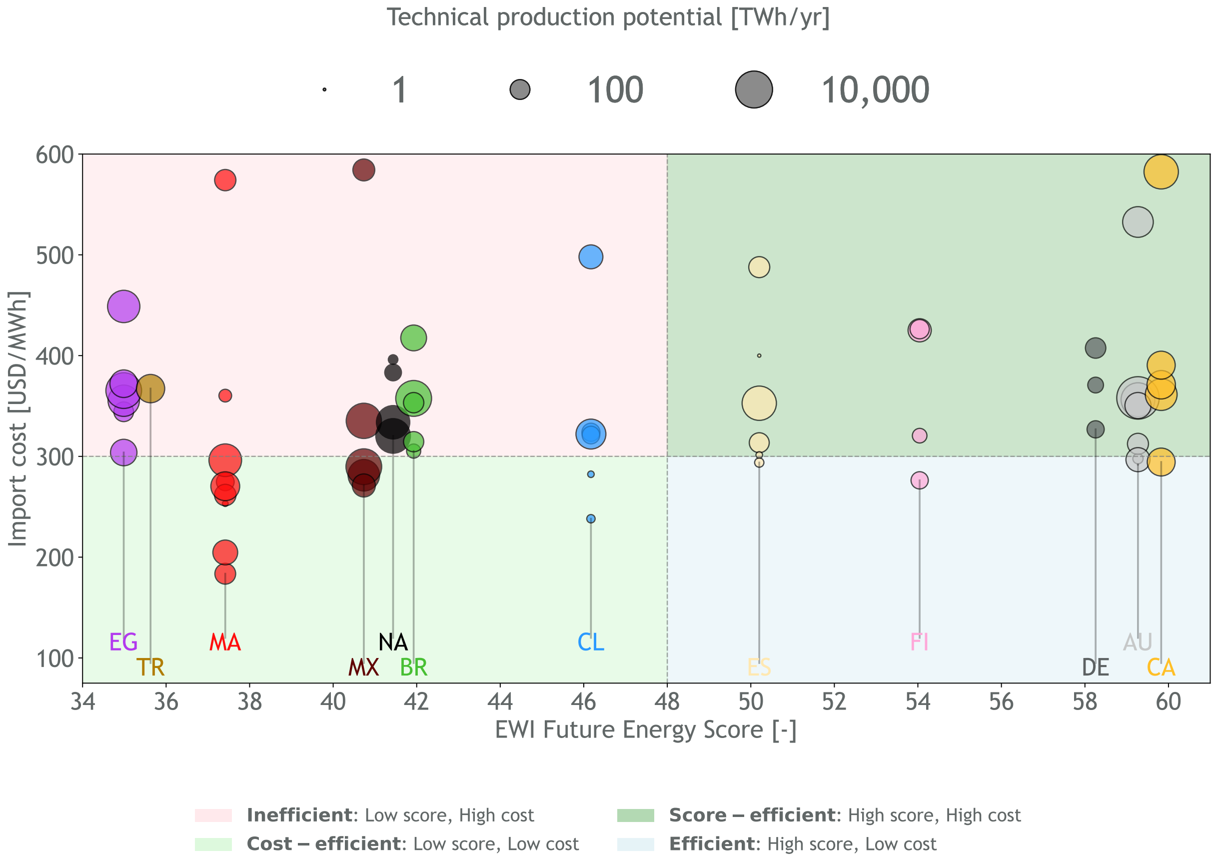

Figure 7: Comparison of costs, performance, and technical potentials for green ammonia

The green ammonia supply potential for countries in this cluster is considerably lower compared to supplying green hydrogen. At the same time, energy-specific supply costs for green ammonia are higher than those for green hydrogen, mainly due to the production process of the ammonia synthesis. Notably, Germany is not located in the efficient cluster for green ammonia compared to the case for green hydrogen, indicating that self-supply with green ammonia may not be efficient.

Score-efficient cluster This cluster contains all countries with a performance score of over 50, and with very high green ammonia production potentials but at relatively high supply costs, ranging between 300 and 582 USD/MWh. More than 90 % of the total production potential in this cluster may be supplied by Australia and Canada at costs comparable to domestic production in Germany, but in much larger volumes.

As supply costs for green ammonia are systematically higher than for green hydrogen (> 300 USD/MWh), most countries which are part of the efficient cluster for green hydrogen shift to the score-efficient cluster for green ammonia.

Cost-efficient cluster The cost-efficient cluster contains Morocco, Mexico and Chile, supplying green ammonia at low supply costs but at the expense of a rather low EFES. The cost of importing ammonia ranges between 184 and 300 USD/MWh, with Morocco and Mexico emerging as the biggest potential suppliers of the analyzed countries. The large potential from Mexico is mostly due to the high capacity factors of its RES, mainly solar power. Imports to Germany from countries in this cluster would all be carried out via ship transport. The three countries pose higher risks for hydrogen investments with potentially lower security of supply than countries in the efficient cluster. Although Chile's performance score is relatively higher than Mexico and Morocco's scores, its supply potential in this cost range is neglectable.

Mexico may be an attractive option for ammonia imports to Germany with relatively high supply potential compared to other countries in the efficient or cost-efficient clusters. Compared to hydrogen imports, Mexico exhibits an advantage as a green ammonia exporter compared to other countries as most countries offer either higher supply costs or a lower performance score (such as Morocco). However, Morocco offers by far the cheapest supply costs.

Inefficient cluster Countries in this cluster are the same as those in the inefficient cluster for green hydrogen, namely Egypt, Namibia, Brazil and Chile. These countries are limited in their green ammonia export competitiveness due to high supply costs and a less favorable EFES performance.

3.3 Discussion

The previous chapter showed the comparison of supply costs with the performance score for potential hydrogen and ammonia suppliers for Germany. Efficient suppliers for hydrogen may be located foremost in Europe. Performance-efficient suppliers may be represented by Canada and Australia, while cost-efficient suppliers may be found in north Africa as well as Mexico. For green ammonia, efficient supply potentials with low costs and a high performance score are very limited.

It is important to note that the definition of the clusters represents a methodological choice. Different threshold values would inevitably lead to different cluster assignments. The supply cost differentiation between low and high costs at 300 USD/MWh was selected as it is often discussed as an approximate upper bound of what consumers may be willing to pay for imported hydrogen in 2030. Likewise, the differentiation between comparatively high and low performance scores was based on the median of the evaluated countries in order to ensure a balanced classification without introducing additional normative weighting.

The EFES may change over time due to unforeseen events, especially within the political and social sub-indicators. The EFES should therefore be interpreted as a structural orientation reflecting current country conditions that may enhance or threaten supply security and export capability, rather than as a static forecast. The robustness of the performance score can be assessed with sensitivity analyses or periodic updates, particularly in volatile geopolitical environments.

Decision-makers should note that the EFES performance score represents a theoretical and aggregated indicator, while the actual attractiveness of an export country also depends on project-specific and contractual characteristics. Relevant factors include contract duration, price indexation mechanisms, risk-sharing arrangements, financing structures, and potential government support schemes. Therefore, investment decisions should combine the EFES assessment with detailed project-level due diligence.

4 Conclusion

The present analysis emphasizes the importance of incorporating country-specific economic, energy-related, political, and social conditions when evaluating hydrogen import options, rather than relying exclusively on cost-based metrics. In this context, the study does not aim to recommend specific supplier countries. Instead, it underscores the necessity of a broader, performance-oriented assessment framework to support more robust and resilient decision-making beyond a purely cost-driven perspective.

Hydrogen imports from European countries are shown to play a significant role for Germany in achieving comparatively low average supply costs while simultaneously benefiting from higher levels of supply security in exporting countries, particularly where pipeline infrastructure is available. Germany itself emerges as a relevant option within the efficient hydrogen cluster, combining a favorable EFES with relatively low production costs. Consequently, domestic production constitutes a viable self-supply option that may contribute to enhancing supply security. However, given the limited domestic production potential, imports from other EU countries, such as Finland and Spain, represent a complementary strategy. At the same time, the available supply potential in these countries at competitive cost levels is constrained, and a substantial share of production is likely to be required to meet domestic and broader European demand. In contrast, imports from countries such as Morocco, Mexico, or Turkey offer comparatively low supply costs but are associated with higher risks as reflected by the EFES.

In the case of ammonia imports for direct use, the relevance of favorable renewable energy source (RES) conditions increases, as the relative cost contribution of transport is lower. Nevertheless, overall energy-specific supply costs remain higher compared to hydrogen due to the additional conversion costs associated with ammonia synthesis. Only a limited number of countries, including Australia and Canada, are located within the efficient cluster, and their corresponding supply potentials are comparatively small. Countries classified as score-efficient, such as Germany, Finland, and Spain, exhibit higher supply costs, whereas cost-efficient countries, including Morocco, Mexico, and Chile, are characterized by lower performance scores. This distribution indicates that trade-offs between cost efficiency and performance-based criteria are likely unavoidable. Furthermore, the seaborne trade of green ammonia is expected to evolve into a global market, implying that Germany may face increasing international competition for imports from efficient supplier countries such as Australia and Canada.

The distinction between the cost-efficient and score-efficient clusters highlights a fundamental trade-off in the import of green commodities: the implicit value of enhanced supply security. More stable economic, political, and social conditions in supply countries, as well as a higher degree of diversification among supply partners, may justify elevated supply costs from a risk mitigation perspective. However, this trade-off is likely to vary depending on the degree of infrastructure dependency associated with different import routes, as well as the temporal perspective adopted. In the case of pipeline-based imports, infrastructure development is characterized by substantial upfront capital investments, resulting in long-term commitments to specific supplier countries. By contrast, maritime transport may offer greater flexibility. The seaborne trade of energy carriers allows for the potential reallocation of shipments and the integration of new supplier countries at relatively short notice, particularly in the context of an emerging global market for green commodities.

Abbreviations

EFES	EWI Future Energy Score
PCA	principal component analysis
RES	renewable energy sources
WACC	Weighted Average Cost of Capital

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