IRENA
International Renewable Energy Agency

Analysis of

THE POTENTIAL FOR GREEN HYDROGEN AND RELATED COMMODITIES TRADE

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.
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ABBREVIATIONS

CH_3OH	methanol
DAC	direct air capture
DRI	direct reduced iron
H_2	hydrogen
IRENA	International Renewable Energy Agency
kg	kilogram
kW	kilowatt
kWh	kilowatt hour
LOHC	liquid organic hydrogen carriers
MBtu	million British thermal units
Mt	million tonnes
Mt H_2-eq	million tonnes of hydrogen equivalent
MWh	megawatt hour
PV	photovoltaic
SAF	sustainable aviation fuel
t	tonne
TW	terawatt
TWh	terawatt hour
VRE	variable renewable energy
WACC	weighted average cost of capital

EXECUTIVE SUMMARY

This analysis aims to explore the tecno-economic potential for the trading of green hydrogen and its associated commodities such as ammonia, e-methanol and direct reduced iron (DRI) in 2050, using a cost-optimisation approach. It builds on IRENA's 2022 work on hydrogen trade, integrating updated assumptions which reflect the evolving market dynamics, and policy developments.

The analysis extends beyond the trading only of hydrogen, expanding its scope to additional green commodities derived from it. It includes 35 global regions and considers renewable energy potential, infrastructure costs and commodity-specific constraints.

The analysis compares two main scenarios: the "Same WACC Scenario" with all the countries having equal weighted average cost of capital (WACC), and the "Differentiated WACC Scenario" with varying WACC for each country. It includes sensitivities on relevant parameters such as the capital costs for renewable generation and electrolysers and the costs of transport.

The use of scenarios with same and differentiated WACC allows an assessment on how financing conditions impact the competitiveness for trade, separating their influence from geographic and resource related advantages such as renewable energy potential and land and water availability.

This analysis is based on a cost-optimisation assessment that considers natural resource endowments and geographical locations. It does not directly take into account factors such as political stability, economic development or internal institutional framework within a country. Therefore, the results should always be interpreted as pure techno-economic potential, to be embedded in a broader micro and macroeconomic, political, social and institutional context.

According to the results of the analysis, the percentage of demand for green commodities that is traded in 2050 varies for each green commodity from 30% for ammonia and 18% for e-methanol to 14.4% for pure hydrogen and 14% for DRI. Trade in the form of green commodities would account for between 73% and 80% of total projected equivalent green hydrogen trade, owing to lower transport costs and higher efficiency. The analysis also indicates the need for infrastructure throughout the hydrogen value chain. The estimated investment is about USD 2.49 trillion, which includes 4.7 terawatts (TW) of renewable energy capacity, 2.1 TW of electrolysers, and 0.9 terawatt hours (TWh) of battery storage.

In the Same WACC Scenario, the regions of Latin America, the Middle East, North Africa, sub-Saharan Africa and are expected to be the major exporters, based on their abundant natural resource availability. Incorporating differing WACC by country (Differentiated WACC Scenario), countries like Australia, China, and the United States of America are expected to be at the forefront of exports. Irrespective of the cost of financing conditions, Europe, Japan, Southeast Asia, and The Republic of Korea are the regions where a share of demand could be met through imports of green hydrogen and its derived commodities.

The analysis highlights the need for increased international co-operation and policies facilitating a green hydrogen economy. Investments in renewable energy infrastructure should align with national hydrogen strategies but prioritise areas such as electrification, energy access, and essential services. To facilitate global trade, certification and other frameworks need to be standardised.

This analysis underlines the importance of green hydrogen trade in global decarbonisation and economic development. However, realising this potential requires co-ordinated policy action, investment in infrastructure and international co-operation among potential partners. The insights from the analysis could be helpful in defining policies and investment strategies to achieve the goal of a just and inclusive energy transition. The analysis identifies potential new hydrogen suppliers, highlighting an opportunity for countries to diversify their energy sources and enhance energy security.

Section 1

INTRODUCTION

The global energy landscape is undergoing a transformative shift driven by the urgent need to mitigate climate change while ensuring secure and affordable energy supply. The International Renewable Energy Agency (IRENA) 1.5°C Scenario, from its World Energy Transition Outlook (IRENA, 2024a), presents an energy transition pathway aligned with achieving the Paris Agreement targets. It identifies a set of solutions that can be scaled up to limit global temperature rise to 1.5°C by 2050 in a secure and affordable way.

Renewable energy, increased energy efficiency and widespread electrification constitute the basis to achieve the 1.5°C target by 2050 (IRENA, 2024a). Green hydrogen,[1] produced via water electrolysis powered by renewable energy sources, will also play a crucial role, coupling different energy subsectors. To reach decarbonisation targets, the use of green hydrogen needs to increase substantially as compared to the current negligible levels (IRENA, 2024a).

Beyond its role as an energy carrier, green hydrogen can also serve as a clean feedstock, establishing a bridge between renewable electricity and carbon-intensive industrial processes. Green hydrogen has the potential to play a pivotal role not only in the decarbonisation of the wider energy system, but also in hard-to-abate industrial sectors such as the steel and chemical industries (IRENA, 2024b).

The major cost component for green hydrogen is the electricity supply (IRENA, 2022a, 2023), which strongly depends on the quality of the available renewable energy resources, and the capital and financial costs of building renewable energy generation facilities. The trade of green hydrogen and its derivatives[2] can facilitate access to more affordable low-carbon fuels and feedstock from resource-rich regions, supporting global decarbonisation efforts. Trade can also contribute to enhancing energy security and resiliency by reducing dependence on fossil fuels and, through the broader availability of renewable energy resources, diversifying energy suppliers and trade routes.

The trade of green hydrogen and its commodities can strengthen industrial competitiveness in consuming regions by creating opportunities for accessing affordable green hydrogen and its derivatives. At the same time, it can support economic development and diversification in producing regions. By offering an opportunity for countries to cost-effectively access green commodities from locations with abundant resources, where production costs can be lower (IRENA and WTO, 2023), trade also contributes to avoiding inefficient local overbuild.

Developing and emerging economies constitute an important group of countries with abundant high-quality renewable energy resources and available raw materials necessary to produce green hydrogen and its commodities. The export of green hydrogen and derived commodities – if strategically planned to ensure that priority areas such as electrification, energy access and essential services are not compromised – can present

1 *In this report "green hydrogen" refers to hydrogen produced via electrolysis using only renewable energy generation resources. The term "clean hydrogen" refers to hydrogen with low or zero greenhouse gas (GHG) emissions; the definition includes blue hydrogen, produced from natural gas from natural gas with carbon capture.*

2 *Among others: ammonia, e-methanol and synthetic fuels, as well as low-carbon materials produced with green hydrogen, such as direct reduced iron (DRI) for steelmaking.*

an opportunity for sustainable growth and a just and inclusive transition, contributing to the achievement of the Sustainable Development Goals set by the United Nations.

The conditions to create stable demand for green hydrogen and related commodities – as well as to develop the required infrastructure for their production, storage, transport and trade – require strong policy support. Well-designed policies are crucial to facilitate the development of the hydrogen economy, which otherwise might unfold extremely slowly (UNIDO *et al.*, 2024). Policies span the entire value chain and can support its development via optimised tariffs, tax regimes, certification schemes, partnerships for international collaboration and implementation of procurement practices and carbon pricing schemes (IRENA and WTO, 2024).

An increasing number of countries are developing green hydrogen strategies and policies in alignment with their decarbonisation ambitions and goals. As of October 2024, about 56 countries, ECOWAS (Economic Community of West African States) and the European Union[3] have a dedicated hydrogen policy in place, 46 countries worldwide have established national (and supranational) strategies and 8 countries have established roadmaps for the development and deployment of low-carbon hydrogen (IRENA, 2024c). At the same time, at least 21 other countries were involved in the process of defining their own strategies and roadmaps (IRENA, 2024c). Furthermore, regulatory measures like the EU Carbon Border Adjustment Mechanism (CBAM) actively incentivise the production and export of clean hydrogen and green commodities by putting a price on embedded emissions.

The focus of these policies and national strategies varies depending on their natural resource endowments, economies, industries and specific political priorities within the global green commodities market, with countries positioning themselves as importers, exporters or hubs and proposing strategic partnerships to support their objectives (IRENA *et al.*, 2024).

By means of a techno-economic analysis of potential global trade patterns for green hydrogen and a selected set of associated commodities, this report aims to contribute to the further development of national and regional strategies and policies that align with emerging global markets and promoting a just and inclusive participation. The analysis builds on the work developed by IRENA in 2022 (IRENA, 2022a, 2023), adding an outlook to the possible patterns of trade in hydrogen-based commodities, namely green ammonia, e-methanol and DRI, whose roles in supporting the decarbonisation of hard-to-abate sectors have gained prominence in recent years (Brown *et al.*, 2025; Hydrocarbon Engineering, n.d.; OECD, 2025; S&P Global, 2022).

The results of the analysis facilitate the preliminary identification of potential trade partners for green hydrogen and related commodities and their expected flows under different scenarios. The results highlight regions that may be more competitive in producing these green commodities, based on renewable resource availability and associated anticipated costs, as well as the availability of critical raw materials. The analysis also outlines the required infrastructure investment under the assumed conditions.

This report is structured as follows: Section 2 presents the technical methodology, as well as the main assumptions of the model that support this analysis; Section 3 presents the trade outlook and the main findings of the analysis; and Section 4 provides further discussion of the findings as key insights from the analysis.

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[3] *It refers to the 27 member states of the European Union,*

How to interpret the results of this study

This analysis is based entirely on the cost optimisation of the supply of green hydrogen and related commodities, considering natural resource endowments and geographical locations. It does not consider such factors as energy security constraints, political stability or economic development, which may also affect the trade outlook (IRENA, 2022a, 2023).

The analysis uses predefined scenario for demand of green hydrogen and commodities and costs of renewable energy and other infrastructure (electrolyser, transport, commodities production plants), based on previous work from IRENA and recent markets trends and expectations. It focuses exclusively on hydrogen produced via electrolysis using renewable energy and its derived commodities, without considering substitution or competition with other products or pathways.

While the results of this work can support the identification of import and export roles for countries and regions, and with that support the formulation of trade partnerships and diversification strategies for a secure supply, they should be understood only as a techno-economic potential under idealized conditions. To support the development of robust hydrogen policies and strategies, the potential identified in this analysis must be embedded within a broader energy planning process that considers context specific micro- and macroeconomics, political, social and institutional dimensions.

Section 2

SCOPE OF WORK AND METHODOLOGY

This analysis provides an outlook for the trade[4] of green hydrogen and hydrogen-based green commodities in 2050, after the expected rollout and establishment of a green hydrogen value chain. This approach aims to provide anticipatory insights to inform decisions on infrastructure, international co-operation, potential trade partnerships, investment needs and the development of an equitable value chain.

The analysis is conducted using an extended version of the least-cost model developed by IRENA for publication in 2022 (IRENA, 2022a, 2023), adding the trade of green-hydrogen-based methanol and direct reduced iron (DRI). It is important to note that this is a purely techno-economic analysis based on a cost-minimising equilibrium model. It does not consider factors such as energy security, political stability or economic development. Therefore, the results of this analysis should always be interpreted purely on the basis of techno-economic potential, to be embedded in a broader political, social and institutional context.

The scope of the optimisation model covers renewable power generation, hydrogen production via electrolysis and its conversion to the included commodities. Costs for storage and transport are also incorporated into the analysis[5]. The transport costs only consider technological aspects; trade policy-related costs such as tariffs and certification costs are not included.

The potential for developing solar and wind power capacity to produce green hydrogen is based on the resource assessment from (IRENA, 2022a, 2023). In each of the modelled regions, the potential is constrained by the availability of suitable land and of water for electrolysis. Additionally, to prioritise the use of renewable generation in the power sector, the potential to install generation for hydrogen production is reduced according to the expected installed capacity dedicated to other uses of electricity in IRENA's 1.5°C Scenario (IRENA, 2022a, 2023). Based on the remaining renewable energy potential, the required renewable generation capacity to exclusively meet the demand from the electrolysers is calculated in the optimisation process. This calculation takes into account the quality of resources by region, according to the datasets developed for the previous work from (IRENA, 2022a, 2022b, 2023).

The trade flows of the commodities are predominantly determined by the cost differential between local and external production, regional demand requirements, and the costs of transporting the carriers and commodities. The model is divided into 35 geographical nodes all over the world, wherein the G20 countries and selected non-G20 countries[6] that could play a significant role in trading hydrogen and its commodities are represented individually. The rest of the countries are aggregated by geographical location (*e.g.* Rest of Asia, Rest of Latin America) (IRENA, 2022a, 2023).

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[4] *Trade is understood in this report to be the cross-border exchange of green hydrogen and associated commodities.*

[5] *The analysis does not include the investment needed to develop new ports. Instead, it assumes the use of existing ports, focusing on infrastructure enhancements in the shipping fleet and related storage and handling facilities.*

[6] *Colombia, Chile, Ukraine, Spain, Portugal and Morocco.*

For this analysis, green commodities are assumed to be products and end uses for sectors and applications that can be decarbonised using green hydrogen, substituting carbon-based hydrogen feedstocks or carbon-intensive processes. In the analysis, three green commodities (*i.e.* ammonia,[7] e-methanol[8] and DRI) are considered. All other commodities or end uses are combined under hydrogen demand. Constraints on raw material availability for producing green commodities are also incorporated, with the geographical granularity used in the model.

In the report, the quantity of each green commodity is expressed in million tonnes of hydrogen equivalent (Mt H_2-eq). In certain instances, this is also referred to as embedded hydrogen.

Over the past few years, the narrative around green hydrogen has evolved from being seen as a broad clean energy carrier that could replace fossil fuels across the entire energy system to being recognised as a strategic solution for last-mile decarbonisation in hard-to-abate sectors where electrification is not physically or economically feasible. At the same time, slower than expected momentum in reducing costs and in deployment have led to revisions in demand projections (BloombergNEF, n.d.; Wood Mackenzie, n.d.). This analysis tries to capture this situation by aligning the assumed green hydrogen demand with recent studies. The analysis assumes a total estimated demand of 260 million tonnes (Mt) by 2050 in the main scenarios. This value is derived from baseline demand levels in 2024, in the modelled regions, for key commodities and potential uses, combined with projected growth through to 2050.

To meet the demand for hydrogen in a country or region, hydrogen can be transported in the form of compressed hydrogen through pipelines or via three liquid carriers, namely a liquid organic hydrogen carrier (LOHC), liquid hydrogen and ammonia. Commodities are transported in their original form.

The applied modelling framework allows the import of hydrogen to produce commodities locally in the importing country. Associated costs and efficiency parameters are incorporated for the transport, conversion and production processes.

An overview of the modelling framework can be found in Figure 1. The inputs to the model are: the solar and wind power resource potential and quality, hydrogen equivalent demand per commodity, availability of raw materials, infrastructure costs, efficiencies, and economic factors such as the weighted average cost of capital (WACC). These input parameters are then used by the optimisation model to determine the potential trade partners, commodity production per region, trade flows volumes and investment requirements. A more detailed presentation of the modelling framework and assumptions used for this work is provided in the appendix to this report.

The analysis considers two main scenarios: one where the risk profiles and WACC are differentiated by country or region according to the assumptions from (IRENA, 2022a, 2023), called the Differentiated WACC Scenario, and one where all the countries are assumed to have the same WACC, called the Same WACC Scenario.

In the Same WACC Scenario the production cost differentials, which determine trade flows, are exclusively driven by the quality of the resource and the capital cost. This allows the identification of the regions that are inherently more competitive for the production and export of green hydrogen and its derivatives. In contrast, the Differentiated WACC Scenario applies region-specific WACC values, allowing for a more nuanced understanding of the trade outlook and the economic evolution of each region based on its current position.

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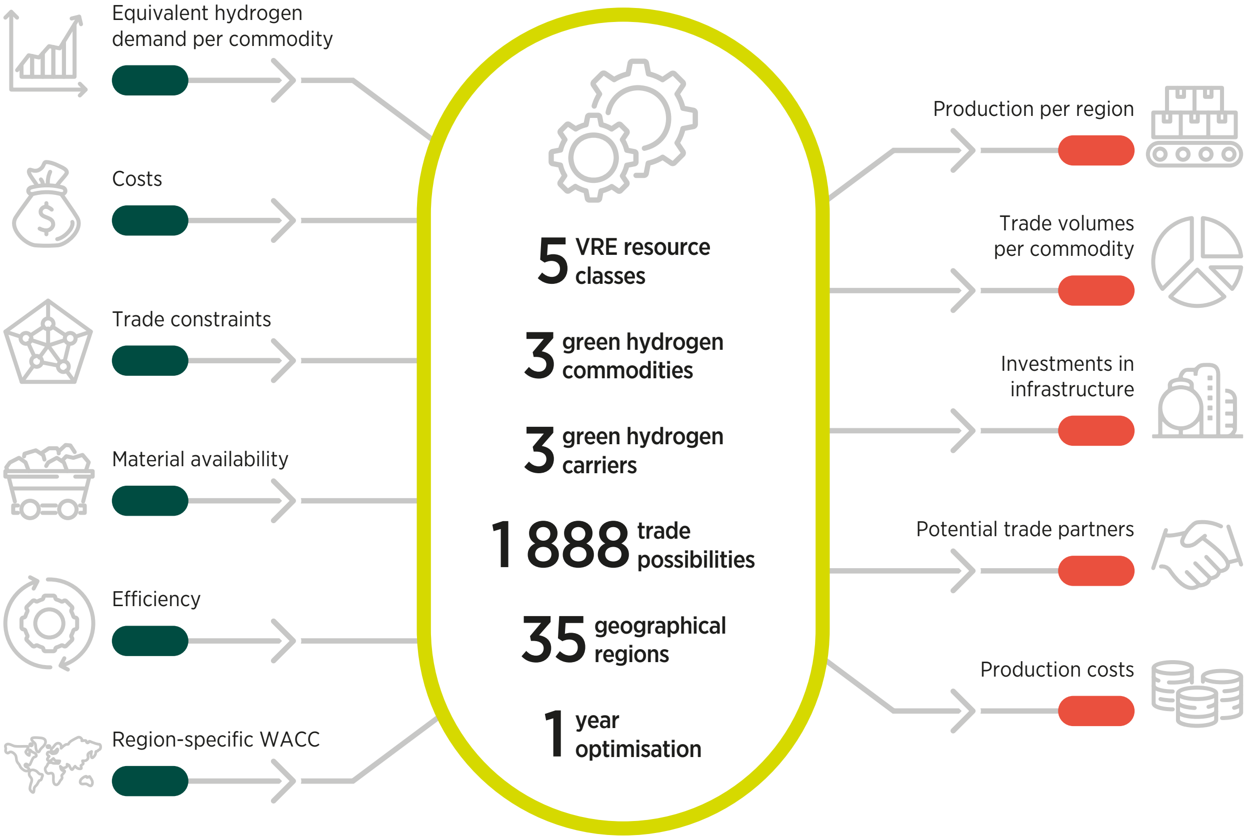
[7] *In the case of ammonia, it is considered as both a commodity with its own demand for use in transport and the chemical sector, and as a carrier to transport hydrogen over long distances.*

[8] *In this analysis only the demand for e-methanol produced with carbon of biogenic origin or direct air captured carbon is considered.*

Figure 1 Methodology of cost optimisation model



Note: VRE = variable renewable energy.

Several sensitivities are analysed to evaluate other possibilities in the trade outlook. These sensitivities include more conservative cost assumptions of electricity generation, transport and electrolysers. Sensitivity analyses are conducted to set upper and lower bounds on investment costs and to analyse variations in projected trade flows, highlighting how regional economic conditions, technological evolution and investment risks can shape the global trade patterns.[9]

[9] *In this report the sensitivities are applied equally to all the analysed regions.*

Section 3

HYDROGEN TRADE PATTERNS

Using the modelling framework and assumptions introduced earlier, this section presents the results of the analysis, providing an outlook of possible patterns for green hydrogen and green commodity trading by 2050.

The analysis compares two main scenarios, which primarily differ in the assumption for the cost of capital. In the Same WACC Scenario all the countries possess equal weighted average cost of capital (WACC), eliminating its influence on the results. In the second scenario, the WACC is different by country according to values considered in IRENA's previous work (IRENA, 2022c).

A. SAME WACC SCENARIO

This scenario considers an optimistic expectation of cost reduction, as in (IRENA, 2022c), for electricity generation, transport and gas conversion plants.[10] It assumes an exact cost of capital at 5% globally to eliminate the impact of differentiated capital costs.

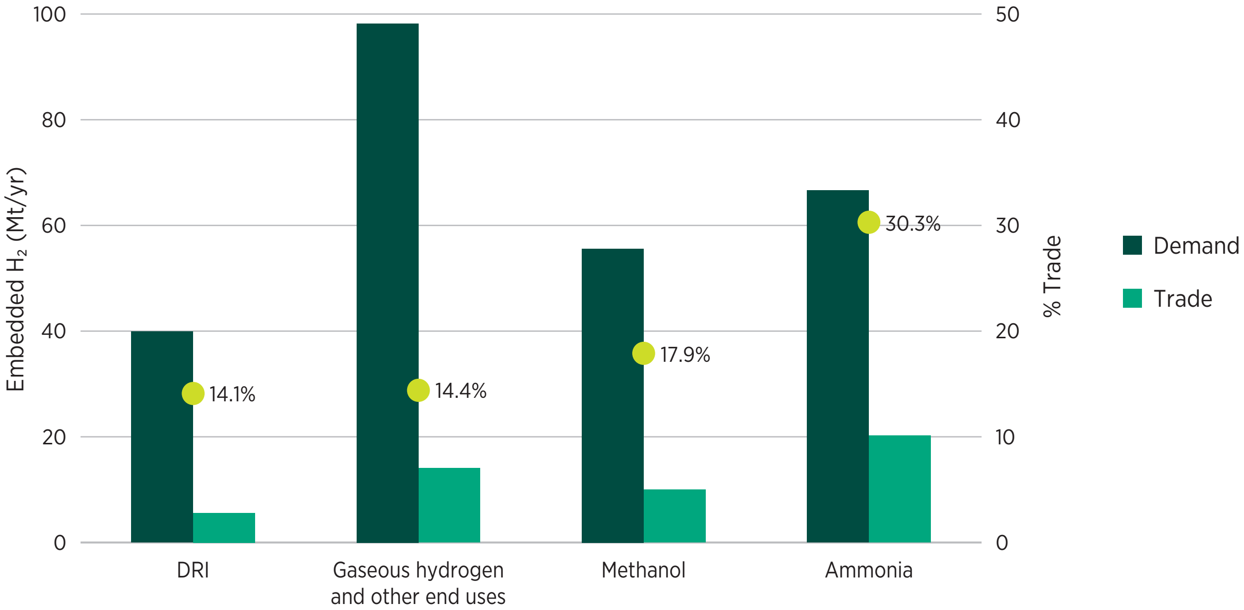
Given the same WACC for all countries and regions, competitiveness arises from having the best renewable resources, availability of materials such as iron ore (required for DRI production) and biogenic carbon (required for methanol production), or overall competitive local investment costs. At the same time, proximity to potential demand centres also plays an important role and provides a competitive edge due to lower transport costs of hydrogen and commodities.

In the Same WACC Scenario, the total volume of traded green hydrogen and related commodities is expected to be around 20% (53 Mt H_2-eq per annum) of the total demand for green hydrogen and related commodities (260 Mt H_2-eq per annum) in 2050.

Figure 2 shows the percentage of green commodity demand that is traded in 2050. For ammonia, approximately 30% of global demand is traded, while 70% of demand is met locally by domestic production within the country or region. In the case of methanol, the traded volume is around 18%, while 82% of demand is met through local production. For DRI, the trade volume in hydrogen equivalent is approximately 14%, while 86% of demand is produced locally. The volume of traded gaseous hydrogen is around 14.4% of total demand; most of this trade would occur through gas pipelines.

[10] *For instance, it is assumed that the capital cost of solar PV will be in the range of USD 225-455/kW, and the cost of electrolysers in the range of USD 215-391/kW.*

Figure 2 Percentage of global demand met by trade in 2050, Same WACC Scenario



Notes: Mt/yr = million tonnes per year; WACC = weighted average cost of capital.

Figures 3 and 4 (with Figure 4 showing each commodity separately) illustrate the expected global trade flow patterns for the Same WACC Scenario. The flows of equivalent hydrogen in the form of different commodities are represented by a unique colour: dark green for ammonia, yellow for methanol, red for DRI, sky blue for compressed hydrogen, light green for liquid hydrogen, and dark blue for liquid organic hydrogen carriers (LOHC). The line thickness represents the volume of green commodity flows in million tonnes of hydrogen equivalent, while circles with a square inside represent the origin of green commodity supply, and circles with a cross inside represent the green commodity demand. Most countries are represented as accumulated regions for the simplified presentation of trade flows.

Under the Same WACC Scenario, Latin America, the Middle East, North Africa, and sub-Saharan Africa are projected to rank among the top regions for exports globally. Major countries and regions with high demand for green hydrogen and its commodities are China, Europe[11], India, Japan, the Middle East, the Republic of Korea, Southeast Asia, and the United States of America. Despite having high demand for hydrogen and its commodities, China, India and the United States of America are increasingly self-sufficient in net trade terms due to the availability of resources, offering reduced opportunities for trading hydrogen commodities. Additionally, Europe, Japan, the Republic of Korea and Southeast Asia, are likely to be significant import markets for hydrogen commodities due to the large cost differences between imports and local production.

The trade of hydrogen in the form of commodities represents almost 72% of the total equivalent hydrogen trade. In the following paragraphs, the position for each commodity and end use – gaseous hydrogen, ammonia, methanol and DRI – is explored. Due to significantly reduced efficiency, transporting liquefied hydrogen or LOHC is only cost-effective in a few instances in Asia, hence it is not discussed in detail here.

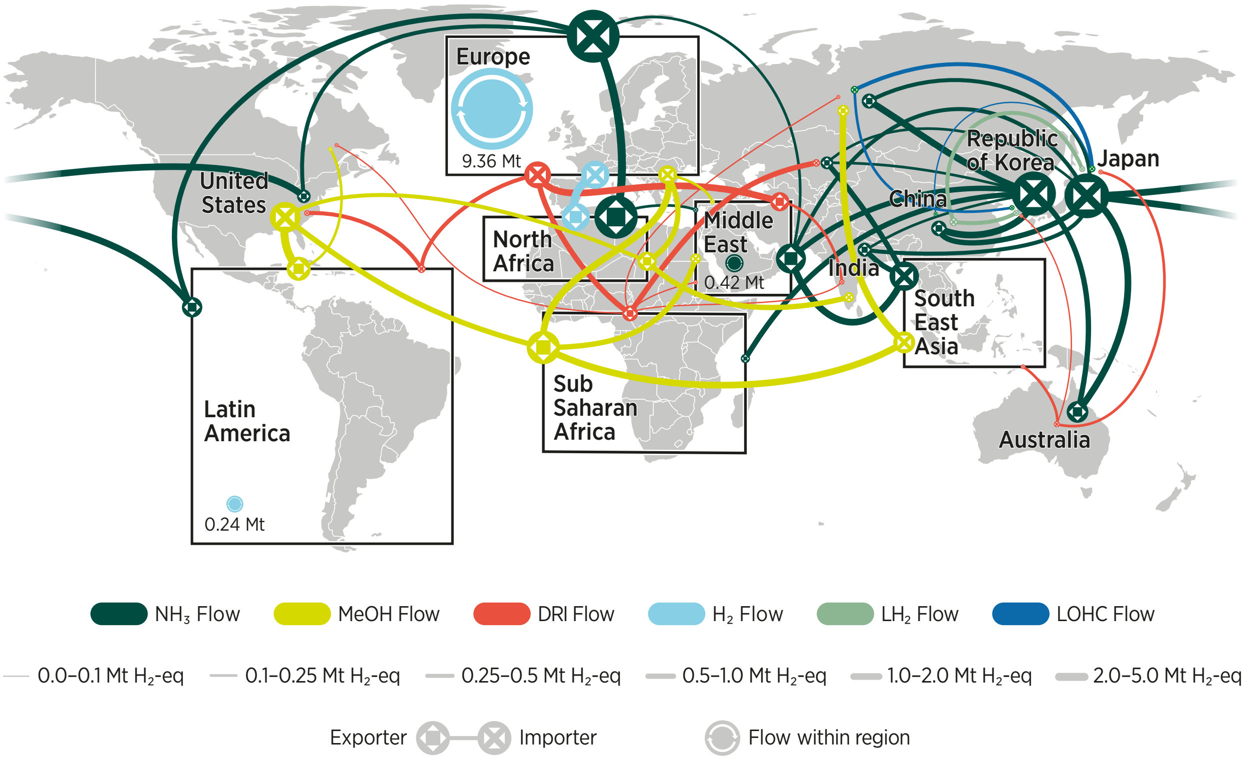
The flows of **compressed gaseous hydrogen** through pipelines in Europe and North Africa represent the majority[12] of the global compressed hydrogen trade in the Same WACC Scenario. This includes intra-regional gaseous hydrogen flows within Europe, produced locally and flowing through the existing comprehensive

11 *All European countries, comprising the EU-27, the United Kingdom, and other non-EU European states.*

12 *It is important to note that intra-regional flows may not be fully captured due to granularity constraints in the analysis.*

pipeline network. Compressed hydrogen exports from North Africa to Europe and among European countries are 3.25 Mt and 9.36 Mt respectively. Other than Europe, there is some trade within Latin American countries in smaller volumes, representing a minor share[13] of the total trade in compressed hydrogen.

Figure 3 Global trade flows in 2050, Same WACC Scenario



Notes: NH_3 = ammonia; H_2 = compressed gaseous hydrogen; MeOH = methanol; DRI = direct reduced iron; LOHC = liquid organic hydrogen carriers; LH_2 = liquid hydrogen.
The thickness of the lines represents the volume of green commodity flows in Mt H_2-eq. Circles with a square inside represent the origin of green commodity supply, while circles with a cross inside represent the commodity demand.
Most countries are represented in regions for the presentation of trade flows.
1 Mt H_2-eq is equal to 5.67 Mt of ammonia, 8 Mt of methanol and 16 Mt of DRI.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city, or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

For **ammonia**, Africa, Australia, Latin America and the Middle East are the major exporters, while Europe, Japan, The Republic of Korea, and Southeast Asia are the major importers. Compared with the other three green commodities analysed in this study, ammonia is expected to be the most traded; almost 30% of its demand would be met through trade.

It is important to note that the analysis does not include the investment needed to develop new ports.[14] Instead, it assumes the use of existing ports, focusing on infrastructure enhancements in the shipping fleet and related storage and handling facilities. Some of the ports considered in the European Union are Algeciras, Hamburg, Lisbon, Livorno, Montoir-de-Bretagne and Rotterdam. For the Russian Federation and the United States of America, two ports each are selected for their extensive geographical access to ensure that the shortest possible distance is considered.

[13] *0.24 Mt in Same WACC Scenario and 2.13 Mt in Differentiated WACC Scenario.*

[14] *The analysis does not consider developing new ports so as to allow the granularity of the analysis to be observed, as explained in previous sections.*

For **methanol**, biogenic carbon availability and the associated costs in different countries and regions are incorporated into the analysis (see Figure A2) (IRENA, 2022a, 2023). Although carbon costs, compared to hydrogen, are smaller contributors to total green methanol production costs, they still have a significant impact on methanol trade flows. Some countries with good renewable energy sources are strained on biogenic carbon sources. In this scenario instead of producing methanol locally through relatively costly direct air capture (DAC) processes, importing methanol from low-cost countries and regions appears to be more economical. As per the results, the United States of America is expected to import methanol from Latin America, Europe from Africa, and Southeast Asia from Africa and The Russian Federation.

Referring to **DRI using green hydrogen**, Latin America, the Middle East and sub-Saharan Africa are expected to be the major exporters. Although iron ore costs are expected to represent a smaller proportion of total DRI production costs than hydrogen, they nonetheless have a significant impact on DRI trade flows. The regions of Latin America and sub-Saharan Africa are expected to have significant iron ore flows (see Figure A3), while the Middle East would import iron ore and produce DRI using its low-cost hydrogen. Sub-Saharan Africa, with its local iron ore, has the potential to produce DRI and export to potential demand centres, while the Middle East would import iron ore from Australia and sub-Saharan Africa to produce DRI and export it to the neighbouring demand centres. As explained briefly in the appendix, it is important to note that the quality of iron ore has also been considered while analysing it for DRI trade (S&P, 2021; S&P Capital IQ Pro Global Metals & Mining, n.d.). Results from the Same WACC Scenario indicate that for the European Union, in this case meeting the majority of DRI demand through direct imports may be more cost-competitive, while a proportion of iron ore is imported for local DRI production.

As highlighted in previous sections, geopolitics, socio-economic considerations and others would be key factors in shaping trade partnerships. Without considering these factors, purely from the cost-optimisation perspective, the results from the Same WACC Scenario indicate the potential for the establishment of an EU-North Africa import/export link. On a global landscape, the European Union is expected to be one of the most significant demand centres for hydrogen and commodities, with North Africa expected to be the significant trading partner (exporter) of the European Union. According to the results from the Same WACC Scenario, North Africa – which includes countries like Algeria, Egypt, Libya, Morocco and Tunisia – has the potential to supply around 18% of EU green hydrogen and related commodities in 2050. North Africa could export around 9 Mt H_2-eq[15] – approximately 5 Mt H_2-eq in the form of ammonia, 3.2 Mt as compressed hydrogen and 0.8 Mt H_2-eq in the form of methanol. Other potential significant potential exporters to the European Union include Latin America, the Middle East, sub-Saharan Africa and the United States of America.

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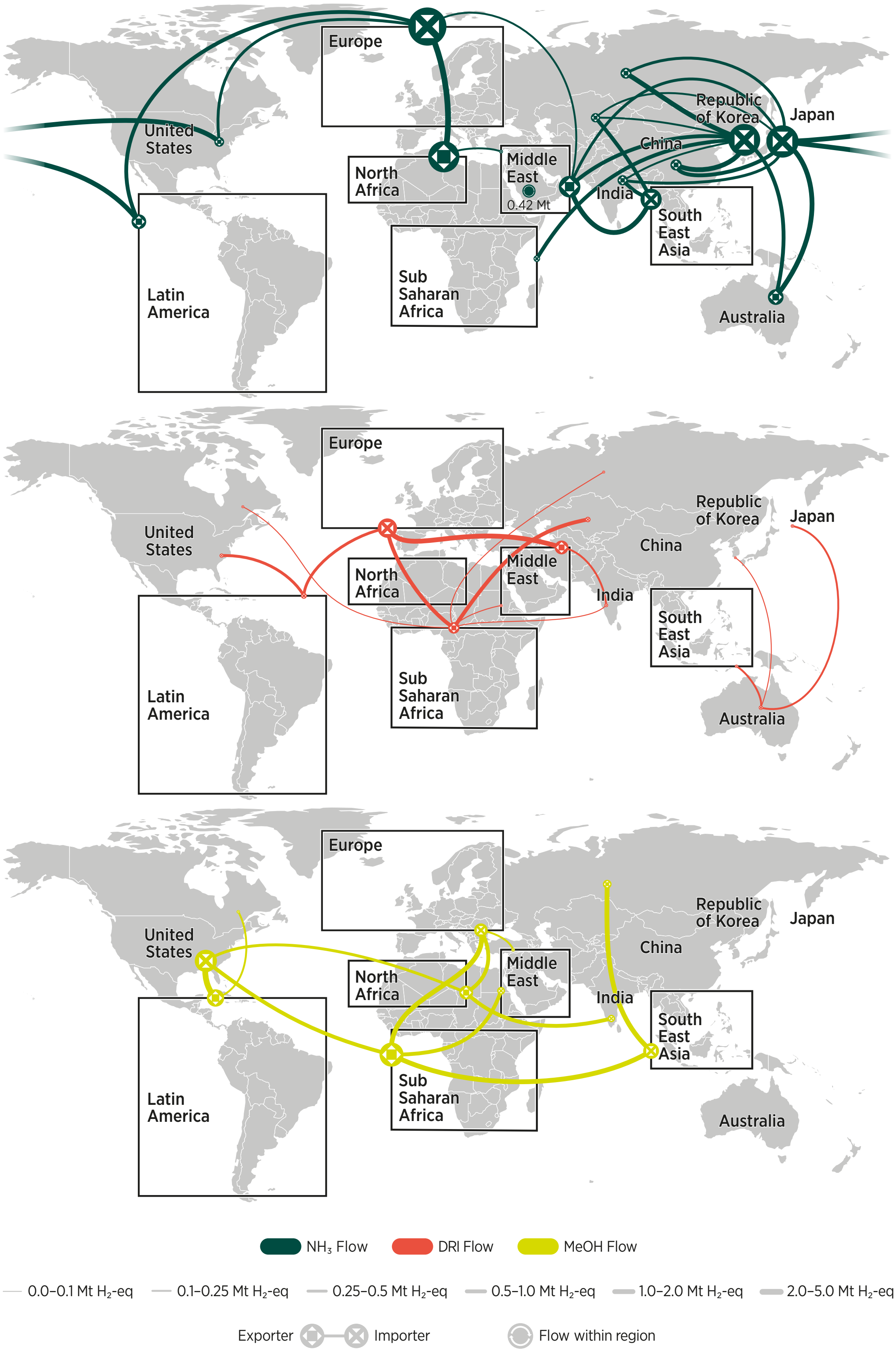
[15] *1 Mt H_2-eq is equal to 5.67 Mt of ammonia, 8 Mt of methanol and 16 Mt of DRI.*

Figure 4 Commodity global trade flows in 2050, Same WACC Scenario



Notes: NH_3 = ammonia (in dark green); DRI = direct reduced iron (in red); MeOH =methanol (in yellow).
The thickness of the lines represents the volume of green commodity flows in Mt H_2-eq. Circles with a square inside represent the origin of green commodity supply, while circles with a cross inside represent the commodity demand.
1 Mt H_2-eq is equal to 5.67 Mt of ammonia, 8 Mt of methanol and 16 Mt of DRI.

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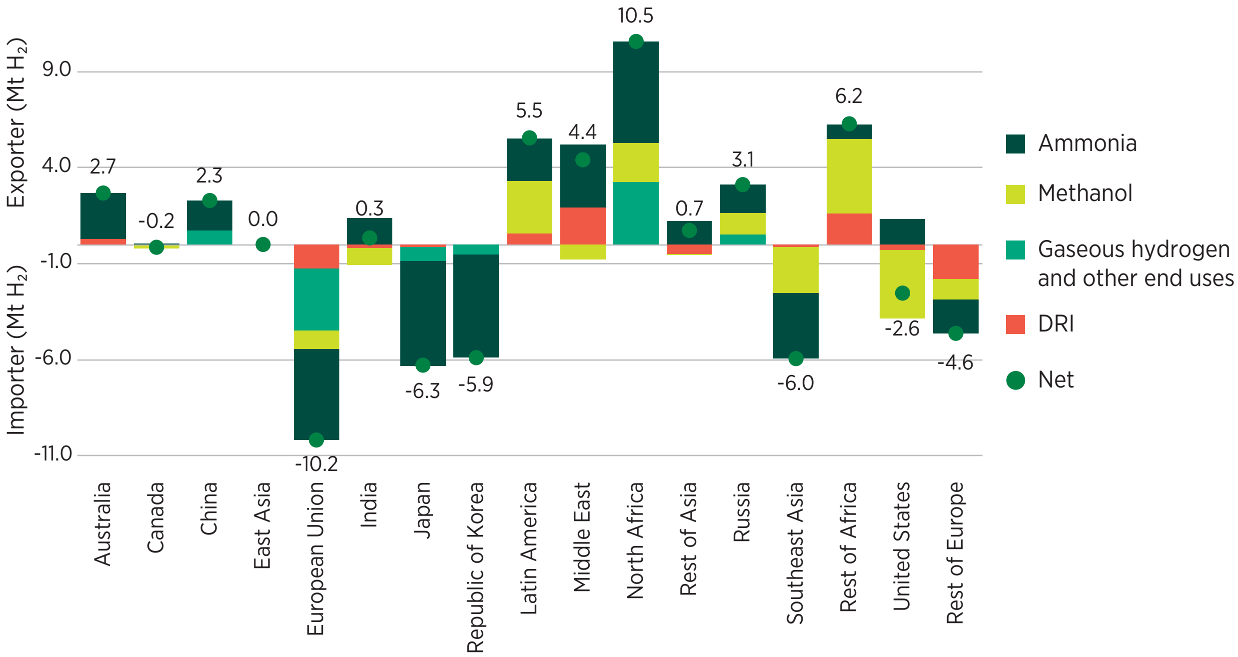
Figure 5 illustrates whether the country or region is expected to be a net exporter or importer of hydrogen and the commodities overall. As per results from the Same WACC Scenario assuming the same WACC for all countries, Latin America, Middle East, North Africa and Sub-Saharan Africa are expected to be the major net exporters of green hydrogen and the commodities while the European Union, Japan, The Republic of Korea and Southeast Asia are expected to be major net Importers. It is worth noting that the net status as exporter or importer may not be consistent with the status of all the green commodities. For instance, consider the example of the Middle East. The Middle East would import some portion of its demand as methanol, it would export a large amount of green DRI and ammonia, rendering it a net exporter of green hydrogen.[16]

Figure 5 Net importers and exporters



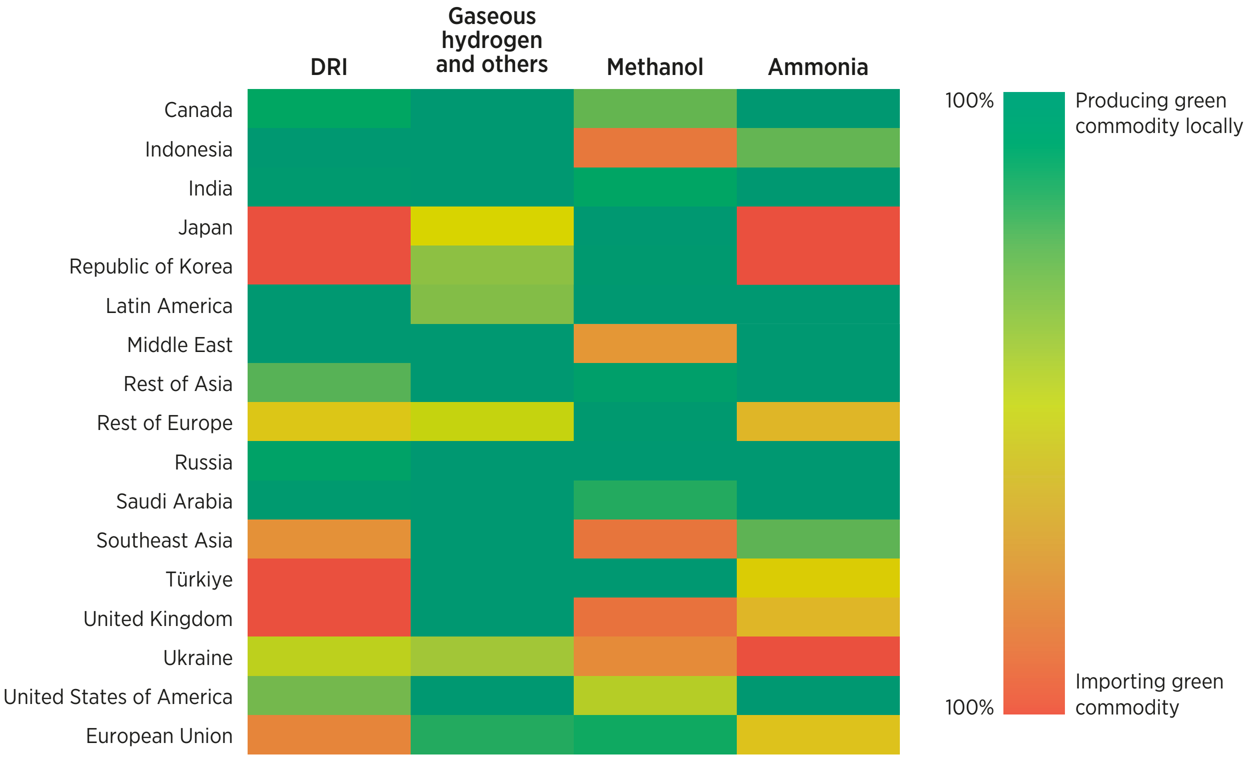
Notes: DRI = direct reduced iron; Mt H_2 = million tonnes of hydrogen.

Figure 6 shows the extent of local production and imports for each green commodity for all countries and regions that import hydrogen in the form of the commodities analysed in this report. Some countries and regions are expected to evolve into self-sufficiency and exports. They are Argentina, Australia, Brazil, China, Chile, Colombia, Mexico, Morocco, North Africa, Oceania, South Africa, sub-Saharan Africa, and are not included in the figure.

In the figure, the intensity of the colour is associated with the extent of local production (green) and imports (red) for the hydrogen equivalent of each green commodity. It shows the percentage of the total demand for a hydrogen commodity in hydrogen equivalent that is traded. The self-sufficiency of some countries in one green commodity, contrasted with imports of other green commodities, is shaped by several factors, as discussed in previous sections.

[16] *It is important to understand the results with a deeper analytical approach, particularly since the results are based on global cost-optimisation methodology. The country or region importing one commodity and exporting others may be influenced by several region-specific factors.*
Although the Middle East has good variable renewable energy (VRE) resources, it is considered to be constrained by the availability of biogenic carbon sources, which lead it to import low-cost methanol from sub-Saharan Africa – the region abundant in both VRE source and biogenic carbon sources.

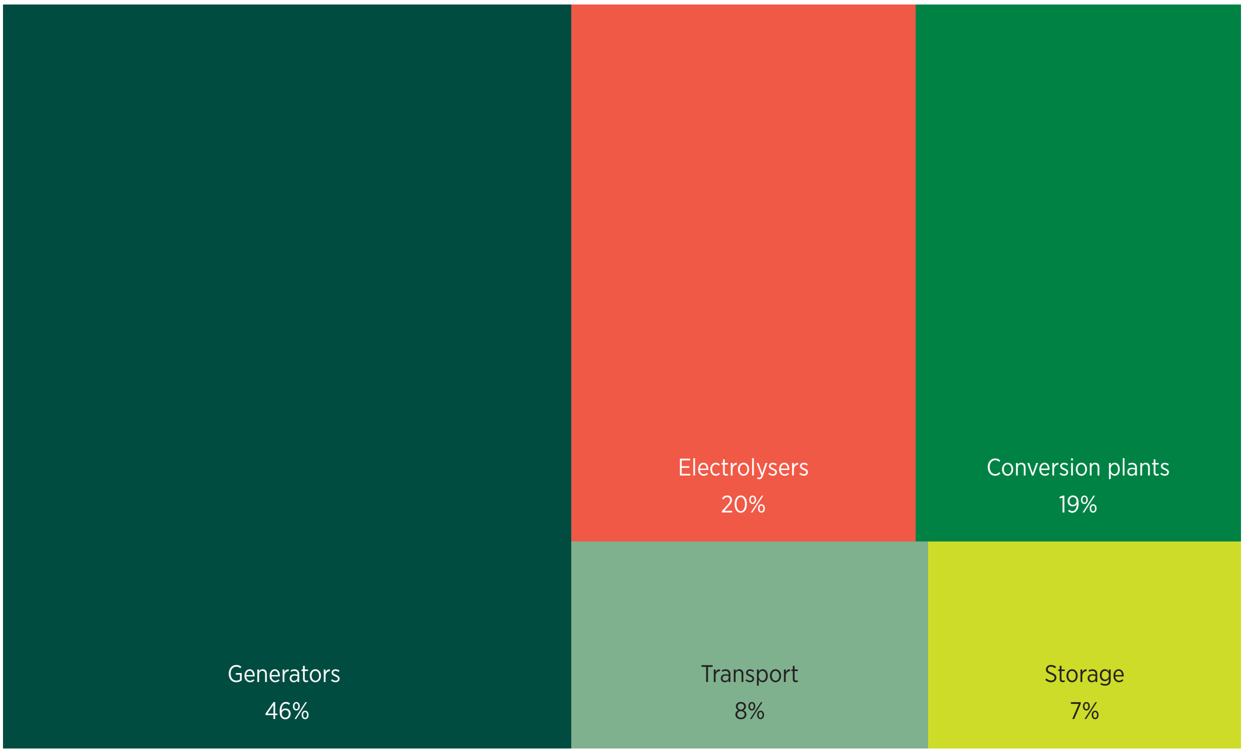
Figure 6 Balance of local production and import of commodities



Notes: Self-sufficient and exporting countries/regions are not included in the figure. They are Argentina, Australia, Brazil, China, Chile, Colombia, Mexico, Morocco, North Africa, Oceania, South Africa and sub-Saharan Africa.

Trading green hydrogen and associated commodities involves building infrastructure across the entire value chain, from power generation and electricity storage, to electrolysis, and all the way to transport (through pipelines and ships), hydrogen storage, and conversion plants (see Figure 7). Under the assumed conditions infrastructure must grow from almost nothing today to supply estimated green hydrogen and commodity demand of 260 Mt H_2-eq by 2050. According to the results of the analysis, investment of approximately USD 2.49 trillion would be needed to build the infrastructure. This investment is associated with 4.7 TW of renewable capacity (mostly photovoltaic [PV]), 2.1 TW of electrolysers and 0.9 TWh of battery storage.

Figure 7 Infrastructure requirements in trillion USD



Notes: Generator = renewable energy plants such as solar PV and wind; Conversion plant = a facility that converts hydrogen into other forms, such as ammonia, methanol, liquid hydrogen and LOHC, and reconverts those carriers back into hydrogen. It also includes components of facilities involved in producing green DRI using hydrogen; DRI = direct reduced iron.

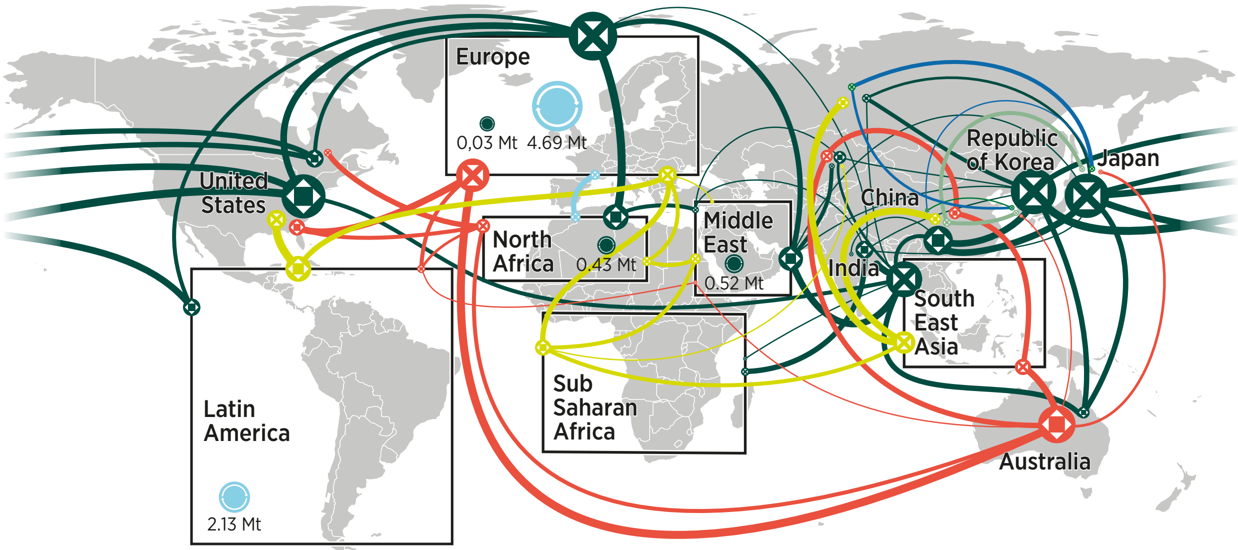
B. DIFFERENTIATED WACC SCENARIO

Green hydrogen projects demand high capital expenditure, requiring substantial upfront investment. The WACC directly influences the cost of financing these investments and plays a critical role in determining the competitiveness of green hydrogen and commodity production. In the Same WACC Scenario, all the countries were assumed to have the same WACC of 5%. In contrast, this scenario considers different WACC for the analysed countries (see A5 in the appendix), aligned with their projected risk profile, in accordance with the factors analysed in (IRENA, 2022c).

As a result, in regions with relatively poor renewable resources, hydrogen produced in contexts with a low cost of capital can become more competitive. Thus, in this scenario such countries produce more significant amounts of hydrogen and related commodities for domestic use rather than relying on imports. At the same time, exports from countries with better financing conditions stand out among countries with similar availability of local resources.

Figures 8 and 9 (with Figure 9 showing each commodity separately) show the global trade flow patterns for the Differentiated WACC Scenario. Compared to Same WACC Scenario, countries with good VRE resources and large economies such as Australia, China and the United States of America are expected to be major exporters of green hydrogen and its commodities.

Figure 8 Global trade flows in 2050, Differentiated WACC Scenario



NH_3 Flow | MeOH Flow | DRI Flow | H_2 Flow | LH_2 Flow | LOHC Flow

0.0–0.1 Mt H_2-eq | 0.1–0.25 Mt H_2-eq | 0.25–0.5 Mt H_2-eq | 0.5–1.0 Mt H_2-eq | 1.0–2.0 Mt H_2-eq | 2.0–5.0 Mt H_2-eq

Exporter — Importer | Flow within region

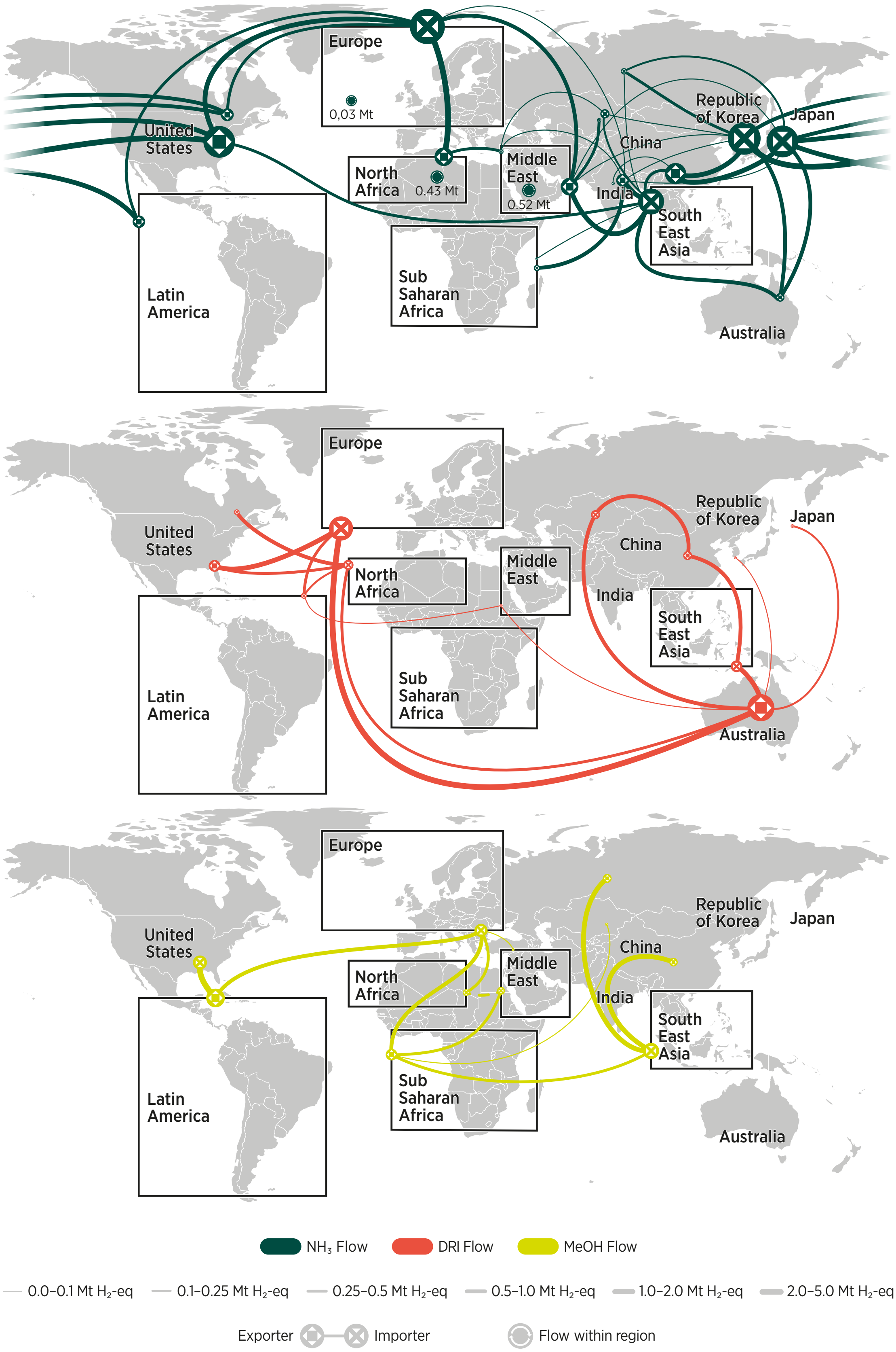
Notes: NH_3 = ammonia; H_2 = compressed gaseous hydrogen; MeOH = methanol; DRI = direct reduced iron; LOHC = liquid organic hydrogen carriers; LH_2 = liquid hydrogen.
The thickness of the lines represents the volume of green commodity flows in Mt H_2-eq. Circles with a square inside represent the origin of green commodity supply, while circles with a cross inside represent the commodity demand.
Most countries are represented in regions for the presentation of trade flows.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city, or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

Concerning **ammonia**, China, and the United States of America and to some extent North Africa would be the major exporters. For North Africa, this is because of its close proximity to the European demand and the assumption that certain countries, like Morocco, have competitive costs of capital with respect to other potential providers. The United States of America emerges as the major exporter, exporting large volumes to Japan, The Republic of Korea and Europe. For Europe, North Africa and the United States of America could be the most significant trading partners for ammonia. The major exporters of **methanol** are expected to be Africa, China, Latin America and the Russian Federation. Notable potential trade partnerships that could develop include the United States of America with Latin America, Southeast Asia with China and The Russian Federation, and Europe with Latin America and Africa.

For **DRI using green hydrogen**, Australia would become the top exporter, followed by the United States of America and China. Australia, China and the United States of America, with their lower cost of capital and their material availability, surpass the competitive advantage of the Middle East and sub-Saharan Africa, producing DRI using their iron ore supply and exporting it to demand centres. In this instance, Australia and the United States of America would represent approximately 80% of total exports of DRI using green hydrogen. The Middle East, which was the top exporter of DRI in the Same WACC Scenario, is now a self-sufficient region for DRI, fulfilling its local demand by producing DRI through local production, while importing iron ore from Africa and Australia.

Figure 9 Global commodity flows in 2050, Differentiated WACC Scenario

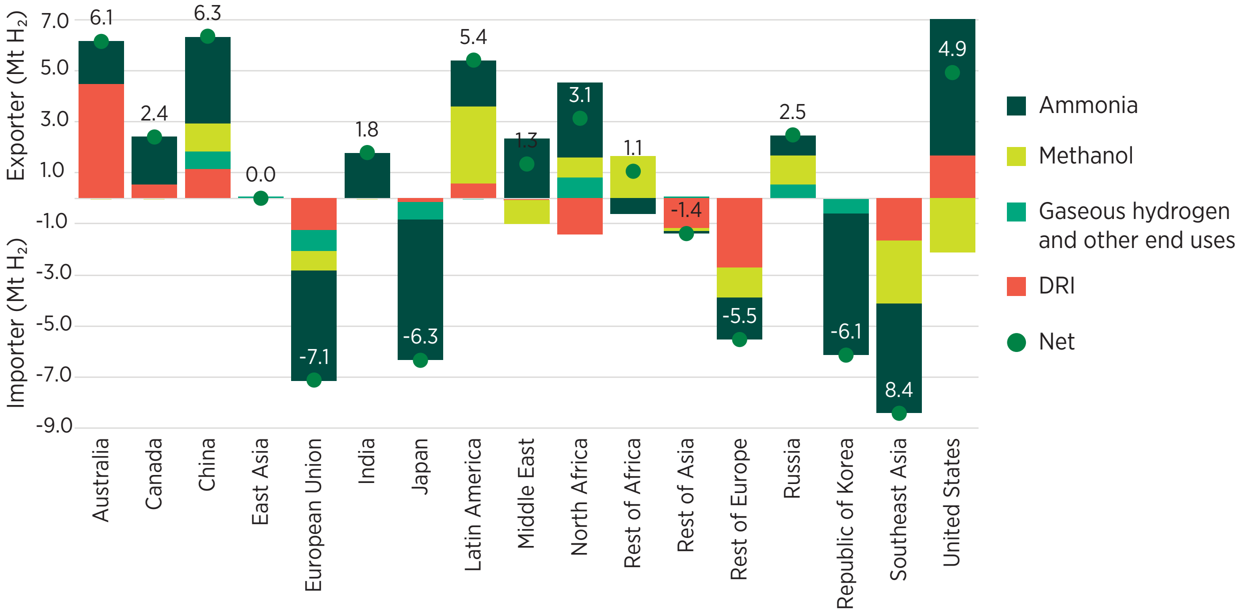


Notes: NH$_3$ = ammonia (in dark green); DRI = direct reduced iron (in red); MeOH =methanol (in yellow).
The thickness of the lines represents the volume of green commodity flows in Mt H$_2$-eq. Circles with a square inside represent the origin of green commodity supply, while circles with a cross inside represent the commodity demand. Most countries are represented in regions for the presentation of trade flows.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city, or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

Referring to Figure 10, Australia, China and the United States of America are expected to be the major net exporters of equivalent hydrogen for green commodities.

Figure 10 Net importers and exporters (Differentiated WACC Scenario)



Notes: DRI = direct reduced iron; Mt H_2 = million tonnes of hydrogen.

C. COMPARATIVE REVIEW OF RESULTS AND SENSITIVITIES

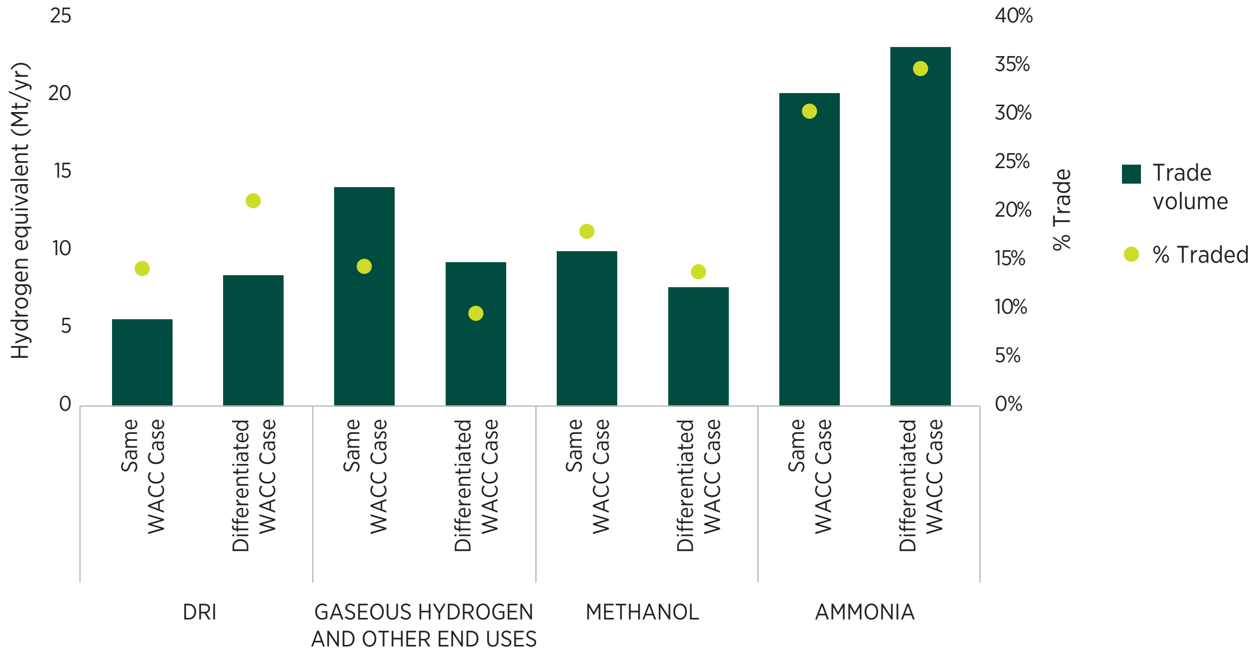
The percentage of a green commodity traded, in hydrogen equivalent, depends on several factors, with WACC assumptions affecting each commodity differently. In the case of **DRI, the traded volume** increased from **14%** in the Same WACC Scenario **to 21%** in the Differentiated WACC Scenario. In the Differentiated WACC Scenario, more stable economies such as Australia and the United States of America become more cost-effective, which leads to the shifting of DRI production away from Africa and the Middle East. In the Differentiated WACC Scenario, the significant quantity of iron ore exports from Australia to the Middle East for processing to produce DRI for export to Europe is reduced. This portion is relocated to Australia, which directly produces DRI and exports it to Europe without an intermediate step of the Middle East as a DRI production centre. Compared to the Same WACC Scenario, iron ore flows are reduced, while DRI trade flows are more dominant, with the DRI to iron ore trade ratio increasing from 1:4 to 1:2.2.

From Same WACC Scenario to the Differentiated WACC Scenario, the traded volume of **gaseous hydrogen** decreases from **14% to 9%.** Most of the compressed hydrogen trade is expected to occur inside Europe, between Europe and North Africa, and within Latin America. In the Differentiated WACC Scenario, the cost differential between producing gaseous hydrogen in North Africa and in Europe decreases, leading to an increase in local green hydrogen production in Europe. This results in reduced flows of compressed hydrogen from North Africa to Europe, thus reducing the overall percentage trade in the form of compressed hydrogen.

Methanol trade volume drops from **18% to 14%** between the Same WACC Scenario and the Differentiated WACC Scenario. The comparative cost advantage of North Africa and sub-Saharan Africa in methanol production is significantly reduced. The reduction in percentage trade is relatively less, due to the introduction of a new methanol supplier, China, which exports to Southeast Asia instead of sub-Saharan Africa. Another reason for decrease in percentage trade is the increase in local methanol production in the United States of America, reducing its methanol imports.

Ammonia trade volume increases from **30% to 35%** between the Same WACC Scenario and the Differentiated WACC Scenario. Some of the countries and regions that were meeting demand locally, or even exporting ammonia in the Same WACC Scenario, start finding it more cost-effective to import cheaper ammonia from Canada and the United States of America in the Differentiated WACC Scenario. This leads to an increase in the total traded percentage for ammonia.

Figure 11 Percentage traded – Same WACC Scenario vs Differentiated WACC Scenario

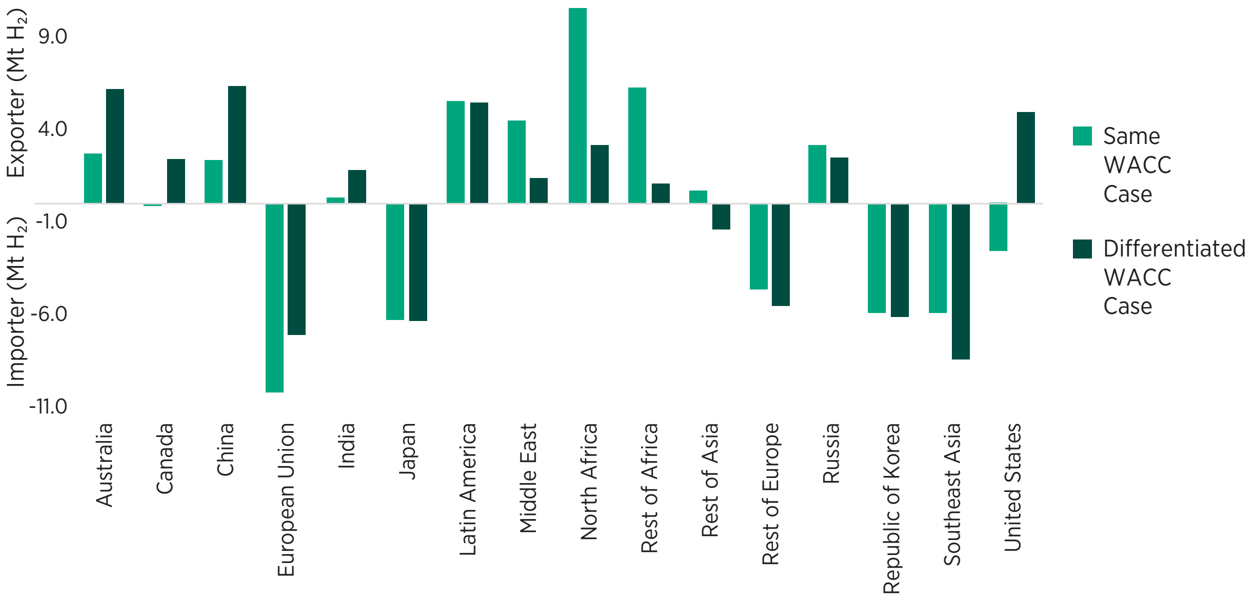


Notes: DRI = direct reduced iron; Mt/yr = million tonnes per year; WACC = weighted average cost of capital.

The top three net exporters of hydrogen equivalent in the Differentiated WACC Scenario are **Australia, China, and the United States** of America, while in the Same WACC Scenario, they are **Africa, Latin America and the Middle East**. Local production for some of the major net importing regions such as the European Union increases, reducing the percentage of demand met by imports in those countries and regions, and a small reduction in the overall trade in hydrogen and its commodities globally.

For instance, net imports into the European Union observed in the Same WACC Scenario of 10.2 Mt become 7.1 Mt. The share of local production of green hydrogen and related commodities significantly increases for the European Union, with only around 19% of demand met through imports.

Figure 12 Comparison of net importers and exporters



Notes: Mt H_2 = million tonnes of hydrogen; WACC = weighted average cost of capital.

In addition to the two main scenarios, Same WACC and Differentiated WACC, where optimistic assumptions of cost reduction were incorporated for electricity generation, transport and electrolysers, the analysis also considered **sensitivities** to these parameters to further evaluate the findings and address the study more comprehensively, covering potential uncertainties.

These sensitivities include conservative cost assumptions for electricity generation, transport and electrolysers for both scenarios. Conservative transport and electrolyser assumptions roughly double the cost of these steps while maintaining an optimistic outlook for the remaining values (*i.e.* a single change). Conservative generation considers higher capital expenditure for photovoltaics of about 20% and for wind of about 10%.

With the **conservative generation** cost sensitivities, net trade volumes are 11% higher in the Same WACC Scenario, and 6% higher in the Differentiated WACC Scenario. Conservative cost assumptions for VRE generation increase local production costs in potential demand centres, creating higher cost differentials and leading to incremental demand being met through low-cost supply, which result in more hydrogen and commodity trading.

Although overall costs are higher, there is no significant impact on overall trade flows in the Same WACC Scenario with sensitivities around **conservative electrolyser** costs.

With **conservative transport** cost sensitivities, net trade volumes are 25% lower under the Same WACC Scenario, and 19% lower under the Differentiated WACC Scenario. Conservative cost assumptions for transport decrease the cost differentials of importing green hydrogen and related commodities into potential demand centres, which leads to increased local production and reduced hydrogen and commodity flows.

An additional sensitivity analysis was conducted by applying an 8% WACC assumption within the Same WACC scenario. The results show a slight reduction in the overall volume of hydrogen and commodities trade. However, trade in ammonia slightly increases in this sensitivity, with some countries exhibiting higher ammonia export volumes and the emergence of a few new trade routes for ammonia.

Section 4

KEY INSIGHTS

This analysis comprehensively considers potential trade options to meet the demand for hydrogen-related green commodities, either through pure hydrogen to produce the commodities in the importing region or through hydrogen-based commodities themselves. Transporting gaseous green hydrogen over long distances may be technically challenging and is found to be cost-effective only for a few specific regions; instead the commodities are generally easier to ship intercontinentally. Therefore, under the analysed scenarios, the trading of commodities is likely to be **more cost-effective** and is more likely to occur than pure hydrogen, with 73-80% of trade occurring in the form of commodities and 20-27% in the form of pure hydrogen under the assumed conditions. This indicates that it would be advantageous to develop additional stages of a sector's supply chain beyond hydrogen production, trading hydrogen-based commodities instead.

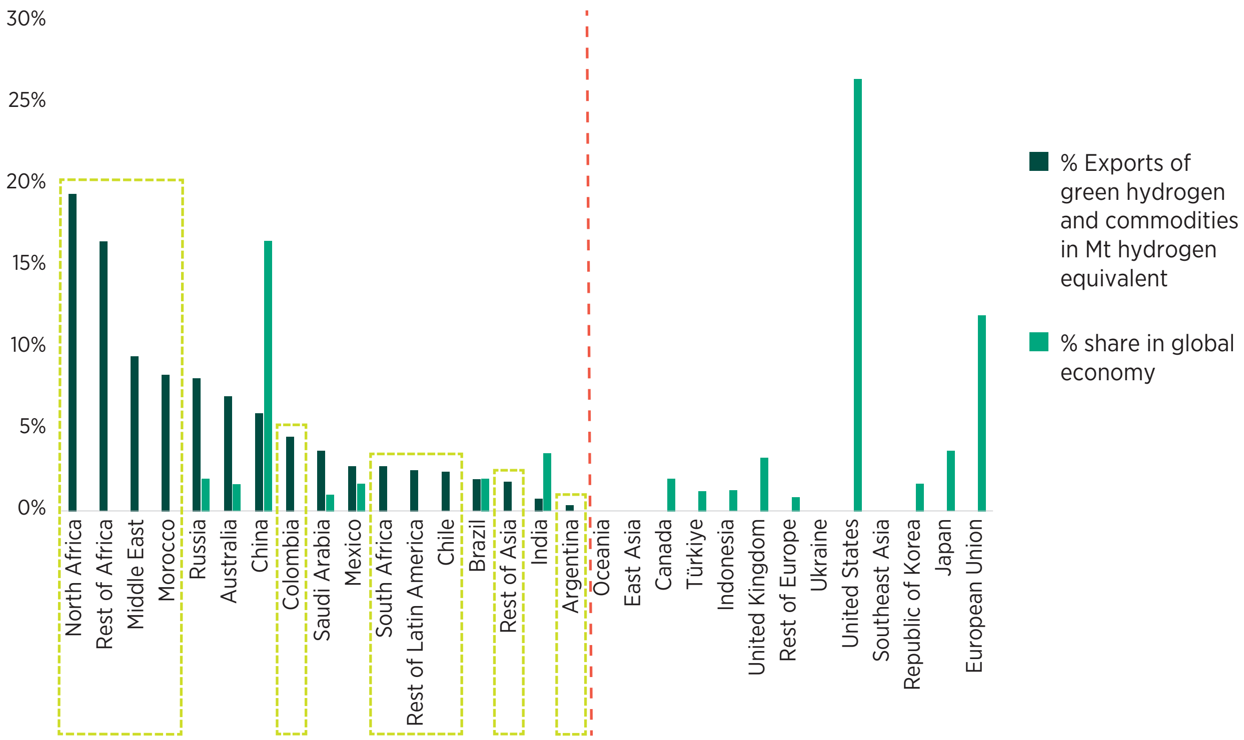
In this context, it is crucial that policy makers take steps to create stable demand for green hydrogen and related commodities and enable the development of international markets for the green commodities. As a result, certification schemes may increasingly be required to guarantee the attributes of the hydrogen-based commodities, and not only for green hydrogen itself. Regulatory frameworks could evolve to establish requirements for greenhouse gas emission intensity associated with the production of green ammonia and green methanol specifically (IRENA, 2024d).

The development of a green hydrogen economy could potentially be beneficial beyond the critical objectives of decarbonisation. If strategically planned to ensure that priority areas such as electrification, energy access and essential services are not compromised, the trade of green hydrogen and related commodities could significantly support the objective of achieving a **just and inclusive energy transition,** particularly from the Global South's perspective. Many developing countries have excellent renewable sources, which could enable them to produce green hydrogen at a lower cost than developed nations, provided they can access financing at competitive rates. The development of hydrogen trade infrastructure provides an opportunity for developing countries to be at the forefront of this global trade, develop economically and increase their contribution to the global economy. This could also help these countries to develop a robust electricity infrastructure alongside the hydrogen infrastructure, as an added benefit.

In Figure 13, the trade results from the Same WACC Scenario are mapped onto countries' current percentage share of the global economy. On the left side of the figure, countries and regions in the dotted box with a comparatively lower share of the global economy **(less than 2%)** are found to contribute significantly to global hydrogen and related commodity trade. Africa and Latin America, could be major exporters of green hydrogen and its commodities under Same WACC assumptions. The African and Latin American share of the global economy is approximately 8.5%; however, as per the results from above section, under a same WACC assumption they have the potential to contribute to around 62% of the global hydrogen trade in a supplier role. Impetus for developing hydrogen infrastructure could be provided to these regions via international cooperation, risk mitigation, and financing instruments to lower the cost of capital, combined with strategically defined expansionary policies to harness renewable resource potential as fully as possible, without affecting priority areas such as the provision of essential services.

Trade can also be beneficial for the economy of developed regions with less abundant resources. Countries such as Japan, which may not have the resources to produce low-cost hydrogen locally, may benefit by importing lower-cost hydrogen and related commodities for their advanced industry.

Figure 13 Potential suppliers in 2050 in the Same WACC Scenario and their global share of GDP in 2024



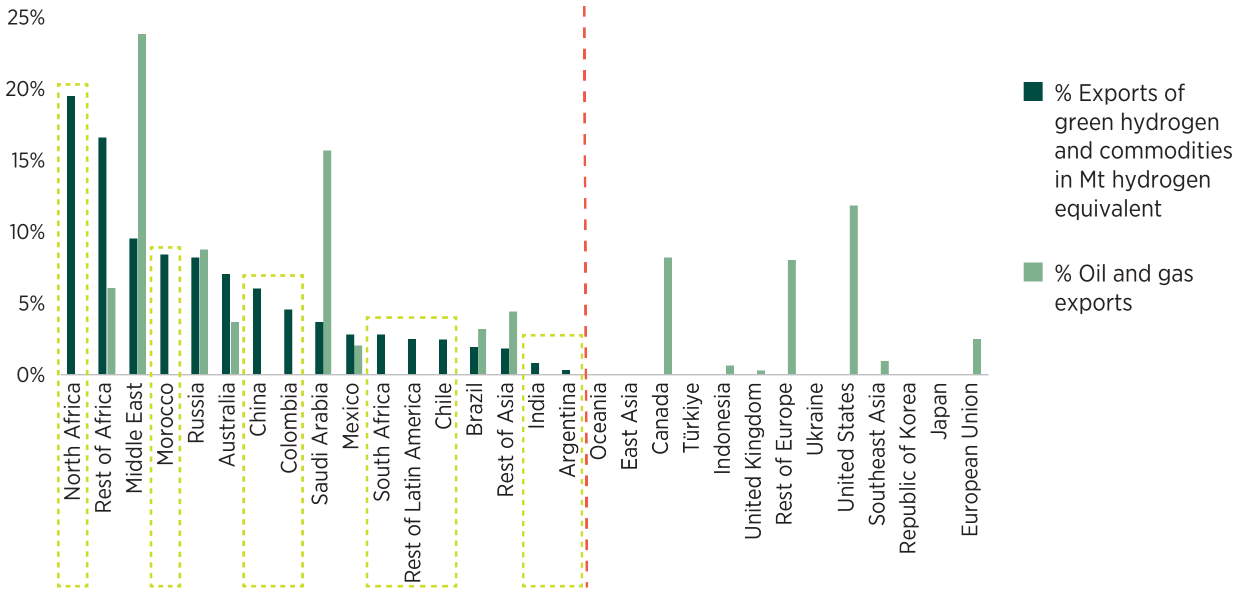
Note: For simplicity, countries and regions with less than 2% share of the global economy are considered to have negligible (0) share; GDP = gross domestic product; Mt = million tonnes; WACC = weighted average cost of capital.

The development of the green hydrogen economy also has the potential to support countries in achieving their **energy security goals**. This can be viewed from two perspectives: lower dependence on fossil fuel imports, and an opportunity for increased energy suppliers on the global market.

Developing regions like Africa and Latin America can utilise their abundant renewable energy potential and reduce their dependence on oil and gas imports to meet their energy demands while diversifying energy supplies. Additionally, the development of trading in hydrogen and its commodities could also be seen as an opportunity for countries to diversify their supply options. The potential trade flows identified in the analysis suggest that the countries likely to take the lead as green hydrogen suppliers differ from those that are the current major suppliers of oil and gas.

In Figure 14, the trade outcomes from the Same WACC Scenario are mapped onto data on the current major exporters of oil and gas (World Bank, n.d.a, n.d.b; World's top exports, n.d.). On the left side of the figure, countries and regions in the dotted box with a comparatively lower share of oil and gas exports **(less than 2%)** in the current global landscape are found to contribute significantly to global hydrogen and commodity trading. Certain countries in Latin America and North Africa, along with China, are identified as expected new entrants in the list of energy exporters. This indicates a potential opportunity for countries to diversify their supply options and become more energy secure.

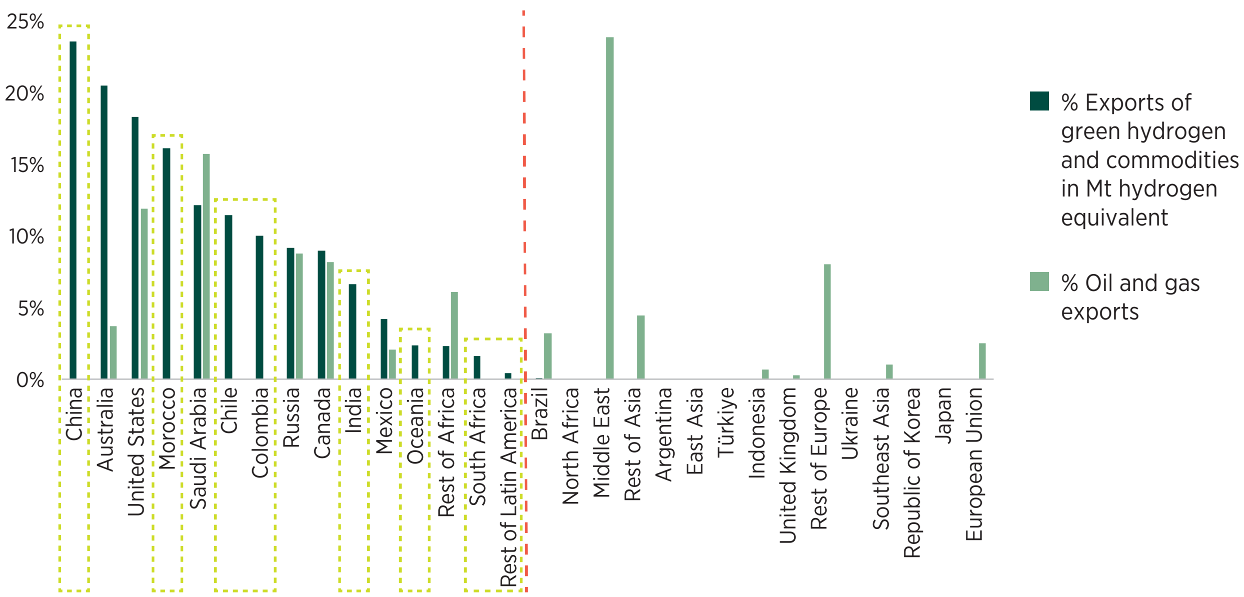
Figure 14 Potential new entrants as energy suppliers in 2050 in the Same WACC Scenario and their global share of oil and gas exports in 2024



Notes: For simplicity, countries and regions with less than 2% share of oil and gas exports in the current global landscape are considered to have a negligible (0) share.

Figure 15 presents the potential impact of the Differentiated WACC assumptions on the insights from the Same WACC assumptions. The trading results from the Differentiated WACC Scenario are mapped onto the current major exporters in the global oil and gas trade. The list of expected new entrants, which again indicates the potential opportunity for countries to diversify their supply options and become more energy secure, changes with respect to the previous case. China and India, along with certain countries from Africa and Latin America, are again identified as expected new entrants in the list of energy exporters. However, North Africa (excluding Morocco) as a region is not seen on the left side of the figure.

Figure 15 Potential new entrants as energy suppliers in 2050 in the Differentiated WACC Scenario and their global share of oil and gas exports in 2024

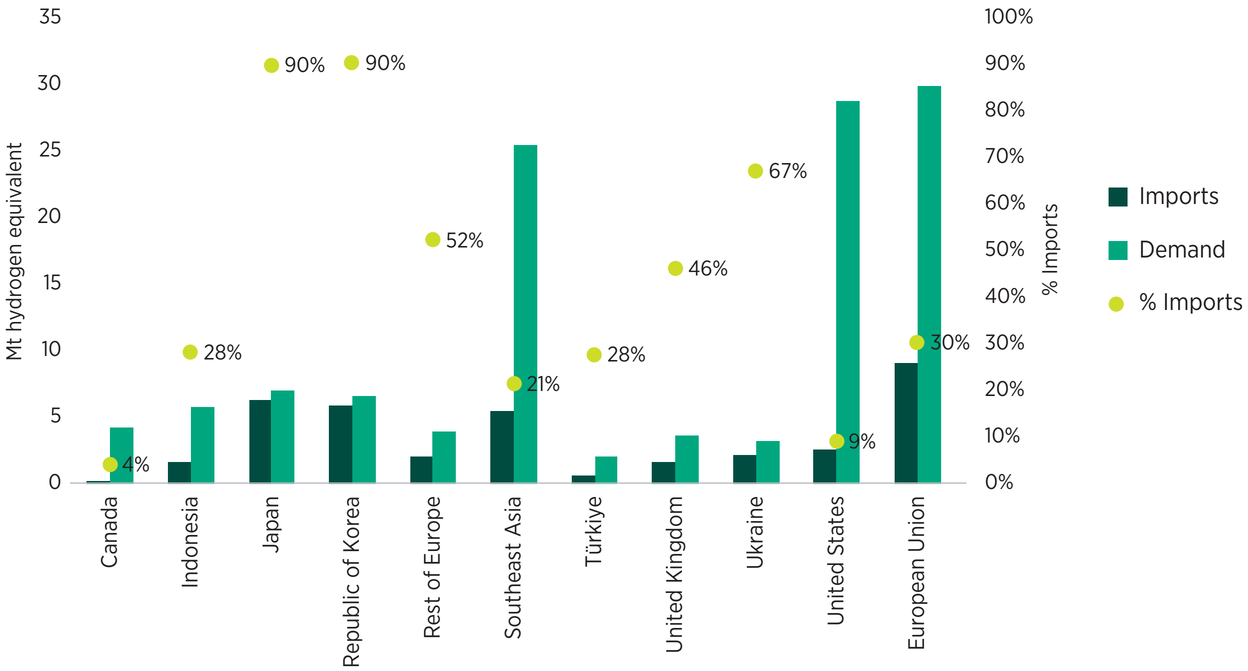


Notes: For simplicity, countries and regions with less than 2% share of oil and gas exports in the current global landscape are considered to have a negligible (0) share; Mt = million tonnes; WACC = weighted average cost of capital.

The WACC, which is dependent on the risk profile of country or region, significantly influences the trade outlook of green hydrogen and related commodities. However, it is also uncertain how the WACC for different countries will evolve over time. Some of the factors that can contribute to the reduction of WACC for a country, specifically for hydrogen and green commodities, are technology transfer through joint projects or cooperation agreements, capacity building, and the use of international financing instruments (IRENA, 2022b). For a just and inclusive energy transition and to drive equitable global progress, there is a need for **global efforts and international cooperation**, to improve the cost of finance for the regions and countries with a higher WACC.

The results of this analysis also emphasise the need for the **customisation of policies and the importance of local infrastructure development**. Around 20% of the total hydrogen equivalent demand is expected to be met through international trade, with a larger portion of the demand (around 80%) to be met locally. This indicates the value of building local infrastructure through robust policies and investment initiatives, supported by strong financial instruments.

Figure 16 Percentage of demand for hydrogen and related commodities met by imports



Note: Mt = million tonnes.

It is also important to highlight that the percentage share of imports and local production differs between countries and regions, which emphasises the need for customised policies and plans. For instance, referring to Figure 16, countries such as Japan and The Republic of Korea, which are likely to import 90% of their green hydrogen and related commodities, would likely need different policies than the European Union and Canada, which expect an import share of around 30% and 4% respectively.

APPENDIX

This study was conducted by expanding IRENA's global hydrogen trade cost optimisation model from (IRENA, 2022c). The model itself does not consider factors such as political stability or economic development, which may affect the trade outlook. Geopolitical relations, trade barriers and other constraints may be incorporated into the model exogenously through specifically designed constraints.

For this analysis, green commodities are defined as products and end uses for sectors and applications that can be decarbonised using green hydrogen, substituting carbon-based hydrogen feedstocks or carbon-intensive processes. In this analysis, three green commodities, *i.e.* ammonia, methanol and direct reduced iron (DRI), are considered. All other commodities or end uses are combined under hydrogen demand.

Methanol can be produced through various production methods, including biomass, natural gas and hydrogen. In this analysis, only the hydrogen-based production method (*i.e.* electrolytic methanol [e-methanol]), which uses hydrogen as feedstock, is considered. The availability of carbon for e-methanol production is considered too. For e-methanol production, carbon can be sourced from biogenic sources or direct air capture (DAC). The expected available quantities of biogenic carbon from different types of sources (fermentation, biogas, pulp, paper, biowaste incineration, etc.) along with their respective costs are included as per IRENA estimates from *World Energy Transitions Outlook* (IRENA, 2023), as shown in Figure A2. In addition to biogenic carbon sources, DAC is also included with its significantly higher cost than biogenic carbon. The trade of biogenic carbon is not allowed in the modelling framework.

For green hydrogen-based steel production, *i.e.* DRI, iron ore flows are considered as per geographical availability (S&P, 2021; S&P Capital IQ Pro Global Metals & Mining, n.d.) as shown in Figure A3. Iron ore quality, which is different in each country, and the resulting requirements for iron processing steps (such as pelletisers), are reflected by the inclusion of cost differentials. It is important to highlight that the trading of iron ore is also included in the modelling framework. This is to evaluate what is more economic to meet the green DRI demand: whether to import it directly, or to import iron ore and green hydrogen separately and produce green DRI locally.

Based on current projections, demand for hydrogen equivalent at each geographical node is estimated for hydrogen and green commodities in 2050. Total global demand for hydrogen and green commodities is estimated to be 260 Mt H_2-eq. The breakdown of green hydrogen and green commodity demand for each country and region is shown in Figure A1. Demand in the European Union is aligned with the Regional energy transition outlook for the EU (IRENA, 2025).

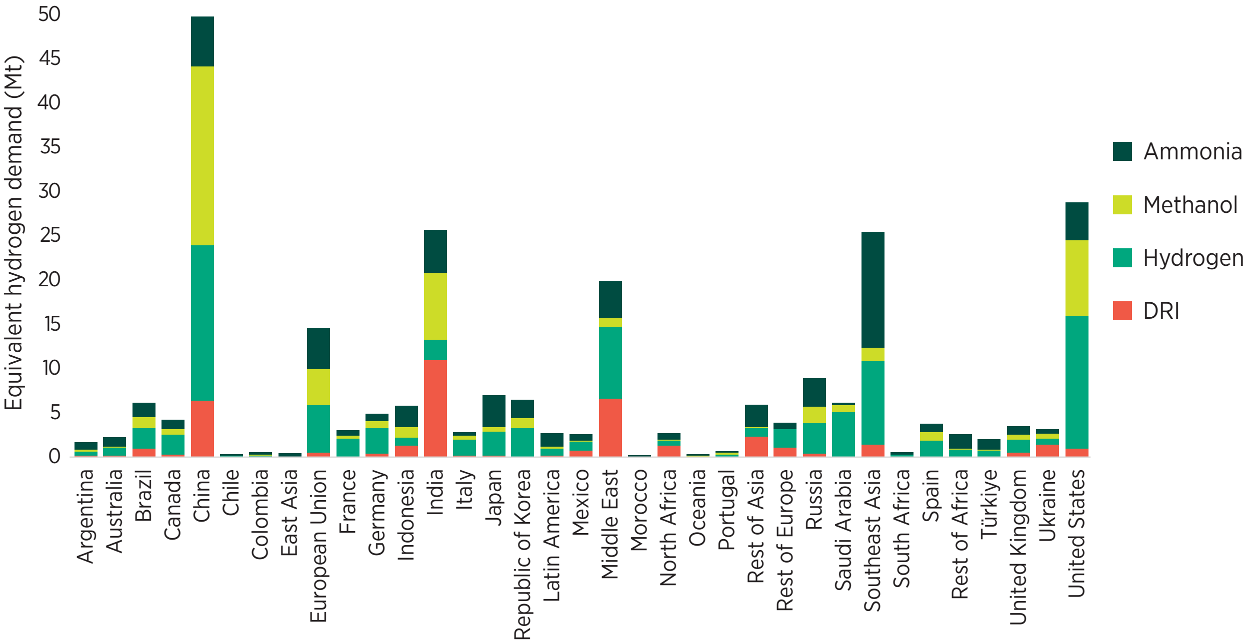
The table below presents the main assumptions implemented in the model.

Topics	Assumptions
Commodities and carriers included in the model for the optimization of production and trade	• Compressed hydrogen gas • Liquefied hydrogen • Liquid organic hydrogen carrier (LOHC) • Ammonia • E-methanol • DRI. The scope of the model is presented in Figure A7.
Time horizon	The model focuses solely on a single-year investment scenario for the year 2050.
Geographical representation	The model granularity encompasses the G20 countries, key countries significant in hydrogen trade (including Colombia, Chile, Morocco, Portugal, Spain and Ukraine), and eight aggregated regions[17] to represent the rest of the world.
Demand	Total global demand per commodity in 2050 under the 1.5°C Scenario in Mt H_2-eq: • Ammonia: 66.7 Mt (7.6 Mt for the European Union) • E-methanol: 55.5 Mt (6.7 Mt for the European Union) • DRI: 39.9 Mt (14.1 Mt for the European Union) • Hydrogen: 98.1 Mt (1.5 Mt for the European Union. The disaggregation of demand for each hydrogen commodity by country/region is based on revised estimates (IRENA work in progress), as presented in Figure A1. For the European Union, demand is aligned with the IRENA EU Outlook 2025 (IRENA, 2025) The methodology focuses on estimating the demand for green hydrogen and derived commodities across key industrial and transport sectors, namely: shipping, aviation, high-value chemicals, fertilizers, and steel. The methodological framework adopted for country- and region-level hydrogen demand estimation is based on the approach used in IRENA's 2022 analysis, with minor modifications to reflect updated data and assumptions. Projections of final energy demand for each sector by 2050, as well as high-level assumptions regarding the share of green hydrogen within production pathways, are aligned with recent literature and scenario studies. Using these inputs, indicative estimates of green hydrogen demand have been developed for each modelled country/region under a 1.5°C scenario for the year 2050. Hydrogen demand in the sectors such as road transport (excluding heavy-duty vehicles), rail transport, buildings, and refining have been excluded from this analysis, as their projected hydrogen demand is assumed to be insignificant. It is important to note that the study does not assess potential competition among different hydrogen (and derived commodities) production routes (e.g., green, blue, grey, turquoise) nor does it consider alternative substitutes for hydrogen-based commodities. The estimate is limited exclusively to the demand for green hydrogen and green hydrogen-derived commodities. Furthermore, hydrogen consumption for the power sector—particularly for seasonal energy storage—has been excluded due to the need for integrated gas and power system modelling, which falls outside the scope of this study. Accordingly, the estimated hydrogen uses in the power sector, projected at approximately 21 EJ/year (equivalent to 175 million tonnes of hydrogen) as per IRENA (2022), has not been incorporated into the demand calculations.
Trade in ammonia	The model accounts only for ammonia reconversion to hydrogen at the importer's end and excludes reconversion for steel and methanol. • Nitrogen costs are implicitly considered in the model • Transport costs are as in IRENA Global hydrogen trade analysis 2022 (IRENA, 2022c).
Trade in DRI	• The production process applied is as shown in Figure A4. Natural gas input is not modelled. • For every tonne of DRI production, 60.5 kg of hydrogen input is assumed. All the trade flows presented in the results section, including that for DRI, are in equivalent hydrogen terms (in Mt H_2-eq).

[17] *Sub-Saharan Africa, Rest of Midde East, North Africa, Rest of Asia, Southeast Asia, Rest of Europe, Rest of European Union, Rest of Latin America, Oceania.*

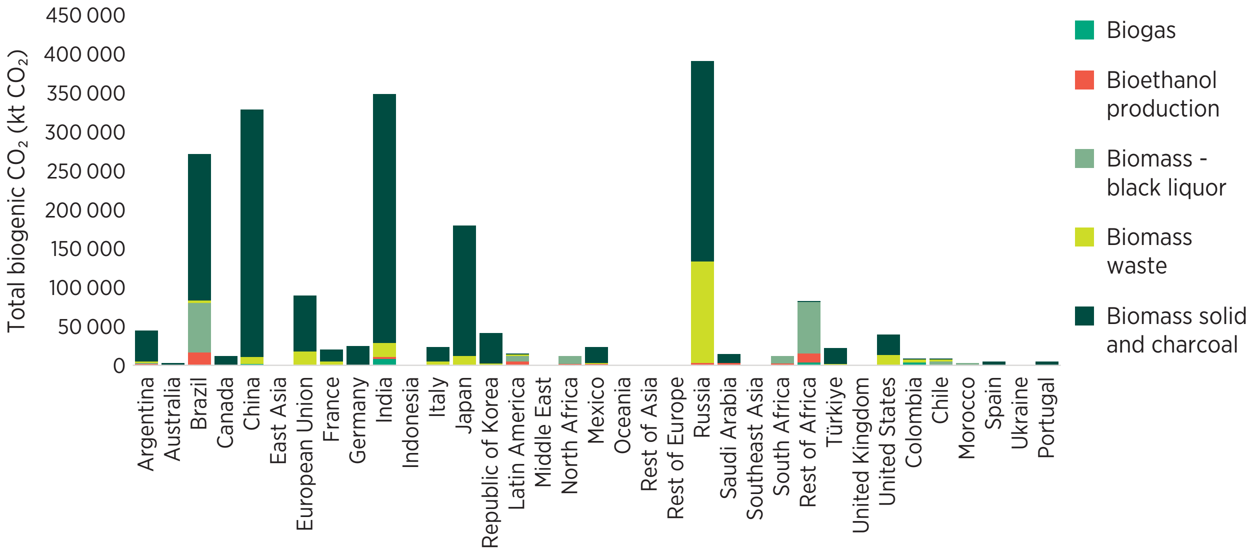
Topics	Assumptions
Iron ore flows	• The iron ore flows in 2050 are estimated according to the output from current mines, taking into account iron ore grades and different products. The output from current mine production has been adjusted to account for a declining rate based on the historical rate of decline of mine production. Estimates also include output from key planned iron ore projects and expansions. • Costs for iron ore are assumed to be uniform across regions, as it is an internationally traded commodity. However, a premium is considered when comparing moderate-grade iron ore with high-grade iron ore, as well as for pellets in comparison with other types of iron ore products. • Iron ore flow data from (IRENA, 2022a; S&P, 2021; S&P Capital IQ Pro Global Metals & Mining, n.d.) are utilised for DRI-exporting countries, as presented in Figure A3.
Trade in E-methanol	• The production process considered is as shown in Figure A5. Water input is not modelled. • CO_2 availability as an input is modelled as shown in Figure A2. • The potential availability of biogenic sources of CO_2 per country is based on biomass transformations for energy use (bioenergy) from the bioenergy flows from IRENA's World Energy Transition Outlook 2024 1.5°C scenario (DES). The production of ethanol and biogas produce as a by-product a high concentration of biogenic CO_2, and the combustion of other types of biomass for heat and power also releases streams of biogenic CO_2, which, if captured, could be used locally or transported to another site for the production of e-methanol. • For each country, the following bioenergy carriers are considered: Bioethanol (production), Biogas (production), Black Liquor (combustion), Charcoal (combustion, assuming only 70% is combusted in centralised locations by 2050), Solid Biomass and Bio-waste (combustion). Note that making these streams available at e-methanol sites requires significant planning (policy, infrastructure etc.) and may have to compete with other uses (such as carbon removals, CCU, the chemical industry, food & beverage and other e-fuels such as e-SAF).
Costs	Capital expenditure assumptions vary according to the country/region, considered for 2050, and are in line with the optimistic cost assumptions from (IRENA, 2022c). • Solar photovoltaic (PV): USD 225-455/kW • Onshore wind: USD 700-1 070/kW • Offshore wind: USD 1 275-1 745/kW • Electrolysers: USD 215-391/kW For the Same WACC Scenario a value of 5% is assumed. For the Differentiated WACC Scenario see Figure A6.

Figure A1 Demand estimates (Mt H_2-eq/year) for green hydrogen and related commodities in 2050



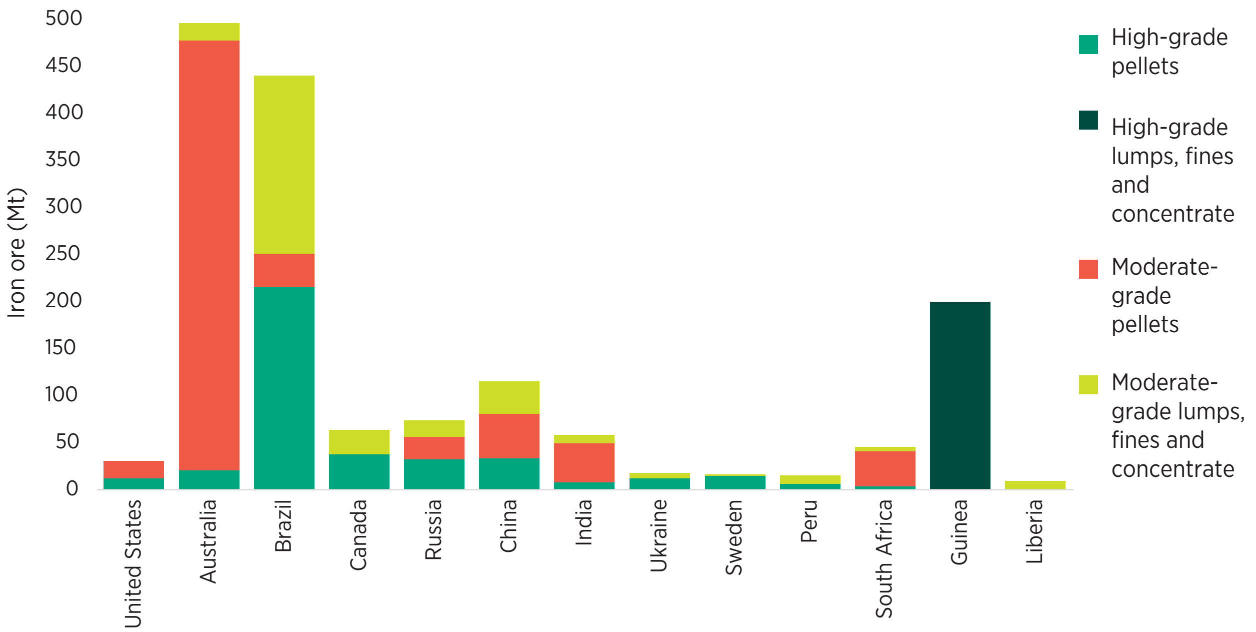
Notes: DRI = direct reduced iron; Mt = million tonnes.

Figure A2 Biogenic carbon sources



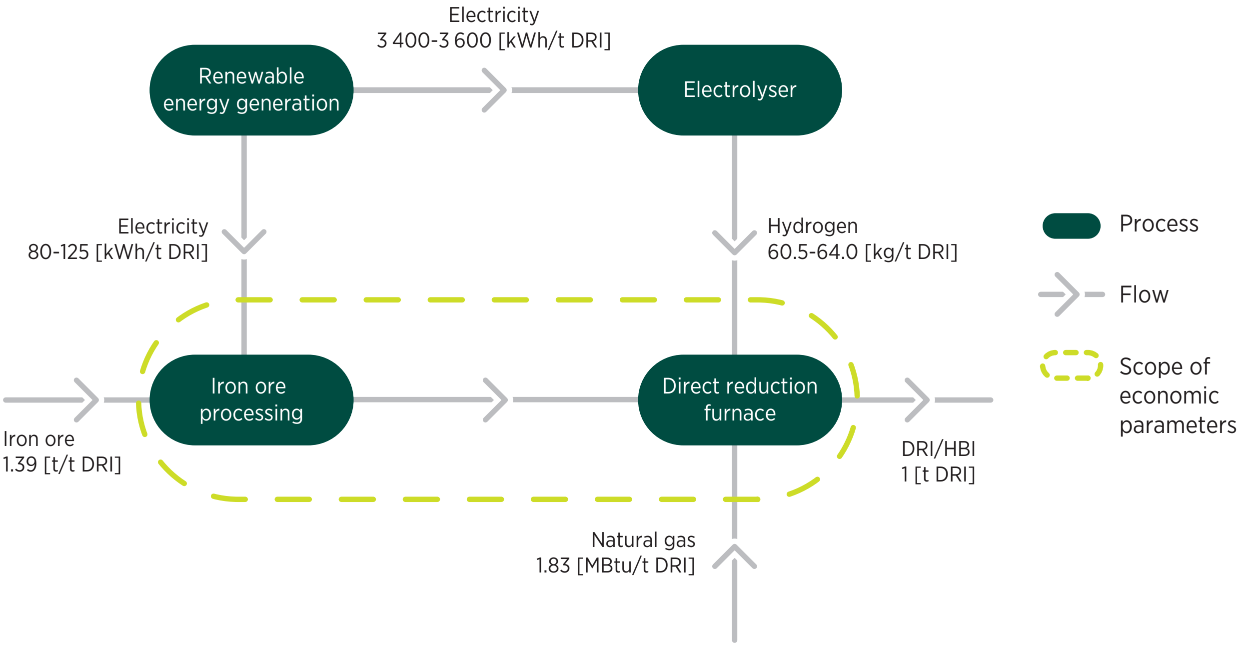
Notes: CO_2 = carbon dioxide; kt = thousand tonnes.

Figure A3 Estimated iron ore flows in 2050



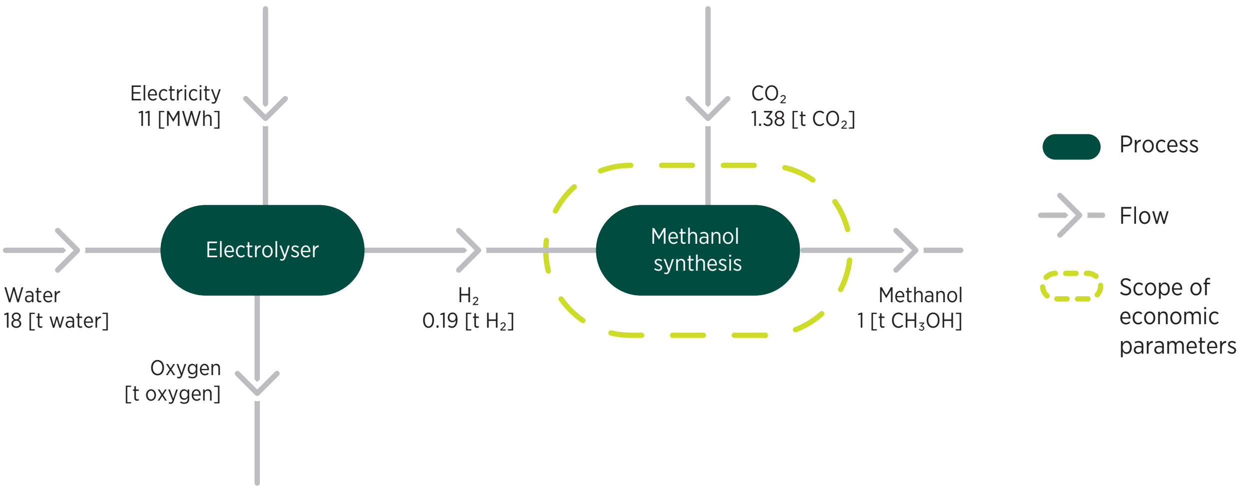
Note: Mt = million tonnes.

Figure A4 Electricity and hydrogen requirements for DRI production



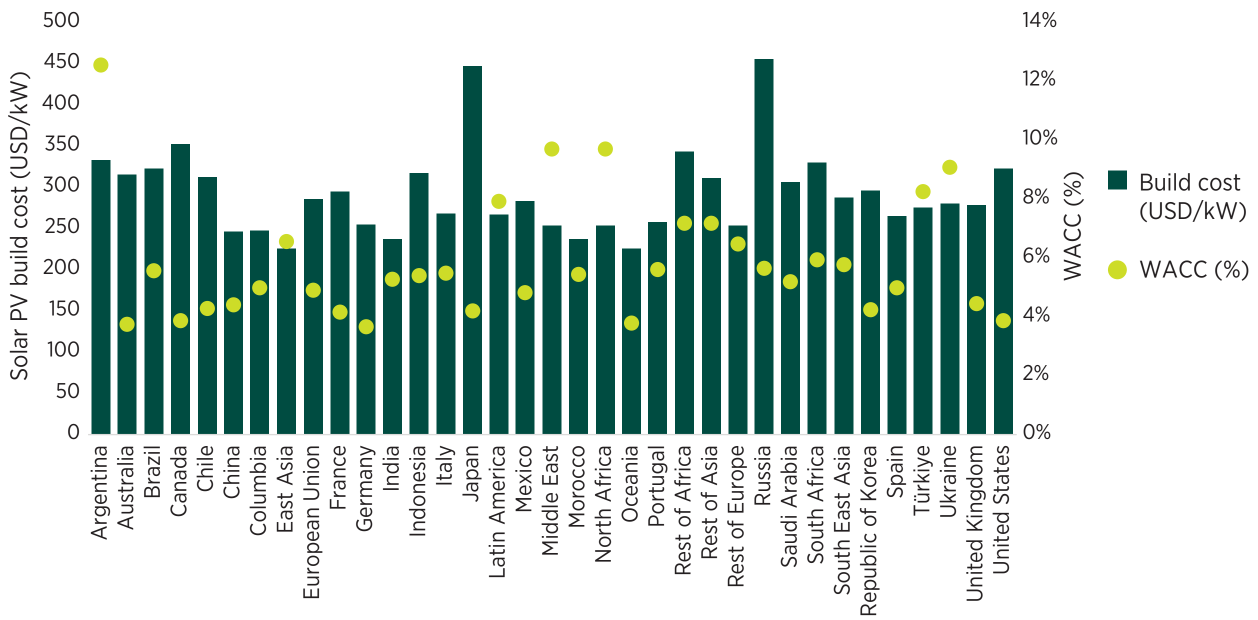
Notes: kg = kilogram; kWh = kilowatt hour; MBtu = million British thermal units; t = tonne.

Figure A5 Electricity and hydrogen requirements for E-methanol production



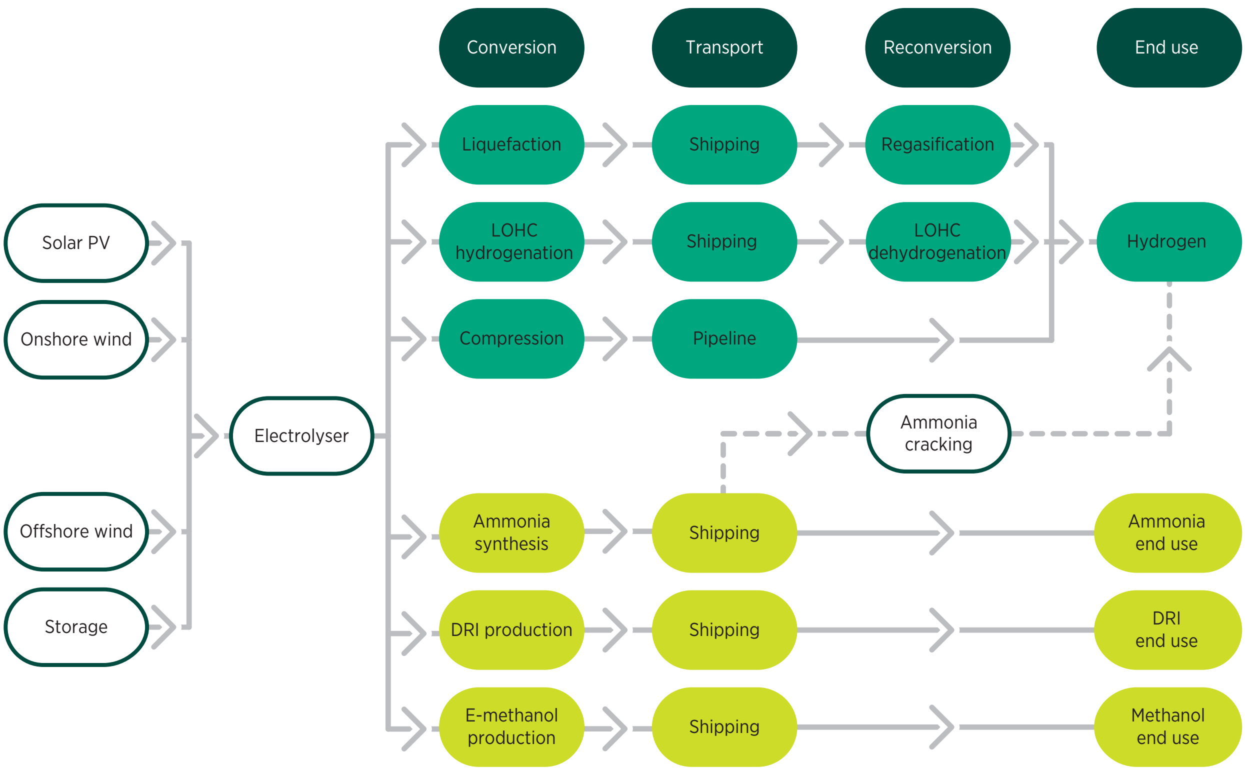
Notes: CH_3OH = methanol; MWh = megawatt hour.

Figure A6 Assumptions for the Differentiated WACC Scenario in 2050



Notes: kW = kilowatt; USD = United States dollar; WACC = weighted average cost of capital.

Figure A7 Scope of model



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