World Trade Organization

IRENA
International Renewable Energy Agency

ENABLING GLOBAL TRADE IN RENEWABLE HYDROGEN AND DERIVATIVE COMMODITIES

ISBN: 978-92-9260-637-4

Citation : IRENA and WTO (2024), *Enabling global trade in renewable hydrogen and derivative commodities*, International Renewable Energy Agency and World Trade Organization, Abu Dhabi and Geneva.

Acknowledgements
This report was authored by James Walker and Ann-Kathrin Lipponer (IRENA), and Svetlana Chobanova, Saira Munir and Rainer Lanz (WTO), under the guidance of Roland Roesch (Director, IRENA Innovation and Technology Centre), Francisco Boshell (IRENA) and Aik Hoe Lim (Director, Trade and Environment Division, WTO).

Several IRENA and WTO staff reviewed drafts of this report, including Arno van den Bos, Francisco Gafaro, Paul Komor, Danial Saleem, Zafar Samadov, Gondia Seck and Patricia Wild (IRENA), as well as Ankai Xu, Daniel Ramos, Devin McDaniels, Jose-Antonio Monteiro, Mateo Ferrero, Michael Roberts, Philippe Pelletier, Roy Santana, Seref Gokay Coskun and Helen Swain (WTO).

The authors also wish to express their sincere appreciation to the following experts for their reviews and insightful feedback: Nawal Yousif Alhanaee (UAE Ministry of Energy and Infrastructure), Laurent Antoni (International Partnership for Hydrogen and Fuel Cells in the Economy), Daria Nochevnik (Hydrogen Council), and Carla Robledo and Han Feenstra (Ministry of Climate Policy and Green Growth of the Netherlands).

Publications and editorial support were provided by Francis Field and Stephanie Clarke, with design by Phoenix Design Aid.

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.

About the WTO
The World Trade Organization (WTO) is the only global international organisation dealing with the rules of trade between its members. At its heart are the WTO agreements, negotiated and signed by the bulk of the world's trading nations and ratified in their parliaments. The WTO's fundamental goal, as set out in the organization's founding agreement, is to use trade as a means to improve people's living standards, create better jobs and promote sustainable development.

This report follows prior relevant work published by IRENA and the WTO, including:

International trade and green hydrogen: Supporting the global transition to a low-carbon economy (IRENA-WTO joint report 2023)

Trading into a bright energy future: The case for open, high-quality solar photovoltaic markets (IRENA-WTO joint report 2021)

Global trade in green hydrogen derivatives: Trends in regulation, standardisation and certification (IRENA 2024)

Global hydrogen trade to meet the 1.5°C climate goal: Trade outlook for 2050 and way forward (IRENA 2022)

Trade Policy Tools for Climate Action (WTO 2023)

CONTENTS

FIGURES

BOXES

ABBREVIATIONS

CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
COP28	28th Conference of the Parties
CTS	Consolidated Tariff Schedules
ENTSOG	European Network of Transmission System Operators of Gas
EU	European Union
GHG	greenhouse gas
Gt	gigatonnes
GW	gigawatt
HS	Harmonized System (of tariff codes)
IHTF	International Hydrogen Trade Forum
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
ITS	1996 Information Technology Agreement
MFN	most favoured nation
Mt	megatonnes
PV	photovoltaic
R&D	research and development
RoW	rest of the world
RSB	Roundtable on Sustainable Biomass Initiative
SAF	sustainable aviation fuel
TESSD	Trade and Environmental Sustainability Structure Discussions
UNIDO	United Nations Industrial Development Organization
USD	United States dollar
WCO HS	World Customs Organization Harmonized System
WTO	World Trade Organization
° C	degrees Celsius

EXECUTIVE SUMMARY

Renewable hydrogen and hydrogen-derived commodities – such as ammonia, methanol and e-kerosene – are expected to play important roles in the energy transition. While most energy consumption can be met using renewable electricity or biofuels by 2050 (IRENA, 2023a), the use of renewable hydrogen and its derived commodities will be required in hard-to-abate sectors, including in industry as feedstocks (*e.g.* chemical manufacturing, fertiliser production, refining, steel manufacture) and heavy-duty transport as e-fuels (*e.g.* in maritime transport and aviation). Their use may account for around 14% of final energy consumption in 2050 (IRENA, 2023a).

Differences in climate conditions and economic circumstances are expected to drive cost variations for the production of renewable hydrogen, hydrogen-derived feedstocks and e-fuels in different geographies. Many countries and regions are considering potential roles in these emerging markets. For those with access to abundant renewable energy resources, exporting opportunities emerge. For those with developed industrial sectors and more limited renewable resources, imports can allow access to a decarbonised feedstocks or fuels. A global market for these commodities is expected to enhance competitiveness and lower total costs by facilitating the development of production facilities where renewable resources are most abundant.

The development of an international market for renewable hydrogen and its derivative commodities will require significantly scaled-up sustainable value chains. Further physical infrastructure is needed; for example, pipelines and shipping facilities are necessary to transport commodities from producers to consumers. Robust market development will be supported by establishing and elaborating plans and strategies for the development of supply chains around technologies and vital inputs (such as water and carbon sources for the production of methanol and e-kerosene). Moreover, the development of sound and coherent policy frameworks will foster market growth, support sustainable production, and facilitate international trade flows. It is also clear that engaging communities and building social acceptance helps to facilitate successful projects.

All of these priorities require action, from various stakeholders, and this report sets out a series of considerations for policy makers enabling international market development and trade in renewable hydrogen and its derivative commodities. These considerations cover areas of energy and trade policy, and the intersections between them. Policy makers are encouraged to consider the resources and tools available to them in their economies, and their specific objectives in terms of international trade in renewable hydrogen and its derivatives. Trade policies such as standardisation and certification mechanisms, government support and procurement, rebalancing tariffs, and carbon pricing mechanisms, can be used to bolster international market development. The evolution of these markets is expected to support green industrial development and job creation, and foster an efficient energy transition.

International collaboration and co-operation is also recognised as being essential to driving these international markets, especially when mechanisms for standardisation and certification are considered. Further work across borders is required in these areas.

INTRODUCTION

THE ROLE FOR HYDROGEN AND ITS DERIVATIVES IN THE GLOBAL ENERGY TRANSITION

Towards 2050, most energy use can be addressed via electrification, using renewable power; in its *World energy transitions outlook* 1.5°C Scenario IRENA projects that 51% of energy demand can be met using renewable power directly in 2050, rising to 67% when contributions from bioenergy are considered (IRENA, 2023a). However, certain sectors that cannot be easily or cost-effectively electrified will require renewable hydrogen or a hydrogen-derived commodity such as ammonia, methanol or e-kerosene to decarbonise. These end-use sectors are often referred to as "hard to abate", as there are relatively few solutions available for addressing their energy demand through renewable means. This is true for both industrial processes in which these hydrogen-derived commodities are used as feedstocks – like chemical manufacturing, fertiliser production, refining and steel manufacturing – and for heavy-duty transport where they will be used as fuels – as in the maritime and aviation sectors. In a net-zero scenario – as sources of low- or zero-emission hydrogen – ammonia, methanol or e-kerosene will be crucial to delivering the comprehensive emissions reductions that are required across the energy system. These end uses account for 14% of total final energy consumption in 2050 being addressed by hydrogen and hydrogen-derived fuels under the IRENA 1.5°C Scenario (IRENA, 2023a).

This report is concerned with renewable hydrogen – hydrogen produced via electrolysis, powered by renewable electricity. Currently, global hydrogen production stands at around 95 megatons per year (MtH2/year), and is primarily derived from fossil fuels without carbon capture and storage. Hence, hydrogen production is a significant contributor of emissions and resultant climate change. Similarly, hydrogen derivatives like ammonia and methanol, which are also largely produced using fossil fuels, also contribute to global emissions. Transitioning these industries to renewable hydrogen sources will be crucial to reducing their environmental impact and aligning them with climate goals.

Joint analysis by IRENA and WTO in 2023 indicates that international trade will play an important role in the development of markets for renewable hydrogen derivatives. These commodities are expected to be easier to transport than hydrogen itself, especially over long distances, as they have a higher volumetric energy density (IRENA and WTO, 2023). Building on these findings, this brief focuses on enabling measures for the development of international markets for both renewable hydrogen, and hydrogen-derived feedstocks and e-fuels, that include renewable ammonia, renewable methanol and e-kerosene. All three derivative commodities have important applications in the current energy system, and are expected to become increasingly important vectors for supplying energy or chemical feedstocks.

INTERNATIONAL TRADE AS A TOOL FOR SUSTAINABLE DEVELOPMENT

Current processes for the production of ammonia, methanol and kerosene rely on the use or direct conversion of fossil fuels. These conventionally-produced commodities are widely traded today, and data is provided in the following sections on the scale of current international markets for each.

Producing renewable ammonia, methanol and e-kerosene at scale will require a readily available source of renewable hydrogen, alongside nitrogen for ammonia, and biogenic carbon (carbon that is sequestered from the atmosphere during biomass growth) for methanol and e-kerosene. The report also considers key enablers to scale up sustainable production and international trade.

The transition to renewable energy offers an opportunity to redefine the boundaries of energy markets and their players. International trade can play a significant role in scaling up the production of renewable hydrogen and its derivatives by matching regions where these commodities are in high demand with regions benefitting from abundant supply. Cross-border trade could save USD 3.7 trillion in investment costs by 2050 by connecting high-demand areas with regions that can supply low-cost renewable and low-carbon hydrogen and derivatives, while helping to unlock some 22 million jobs by mid-century, half of them in emerging markets and developing economies (Hydrogen Council and McKinsey & Company, 2024). This is especially true in economies with abundant renewable resources – many of which are developing economies – where it may be possible to produce these green commodities at a lower cost than elsewhere. In turn, the demand of importing markets can encourage the development of production capacity and innovation to further lower costs. Trade can thus help developing economies realise their green comparative advantages, stimulate sustainable industrial development and increase availability of technology, while at the same time optimising investment and ensuring diversity of supply.

More than fifty governments have presented strategies and policy frameworks for the development of renewable hydrogen production and use in their countries, and some have also considered how to best facilitate the evolution of value chains for renewable ammonia, methanol and e-kerosene (IRENA, 2024a). These value chains cover the production, transport, distribution, and end use of these commodities. At this stage of market development, government policies – from optimised tariffs and tax regimes, through aligning standards and certification schemes and providing government support, to implementing green government procurement practices and carbon pricing schemes – are essential to secure significant, stable demand as well as to incentivise investment, while discouraging the consumption of fossil-fuel derived products.

The optimal policy mix may vary across economies, depending on their natural resource endowments, financial capacities and industry compositions. Each economy's approach will also reflect its specific priorities, such as whether it seeks to position itself as a net exporter or importer of renewable hydrogen, derivatives and/or technologies. The implementation of environmental policies often follows a familiar sequence: initially, governments tend to provide support and regulatory frameworks to foster green technology development and adoption. Once these technologies achieve greater maturity, countries then typically introduce procurement policies, investment incentives, and carbon pricing mechanisms to further drive market expansion and sustainability goals (Linsenmeier *et al.*, 2022).

A patchwork of rules and divergent policy approaches can, however, create trade tensions and jeopardise the effectiveness of these policies. International coordination and dialogue between governments and the private sector are therefore essential in order to create efficiencies and speed up the dissemination of sustainable volumes of renewable hydrogen, ammonia, methanol and e-kerosene. Fostering international cooperation through inclusive multilateral fora can also provide much-needed policy stability and enhance investment security, creating a global market for renewable hydrogen and derivative commodities.

ENABLERS: FOUNDATIONS AND APPROACH

The enablers considered in this report are categorised according to three ‘pillars’ or ‘types’ of measures, which can be developed to support the scaling up of international markets for the renewable hydrogen-derived commodities discussed here. These pillars describe physical, institutional and social enablers. Recommended actions that can facilitate or support the development of international markets for these green commodities are described under these pillars below.

Physical

Physical enablers refer to the deployment of essential infrastructure such as renewable energy generators, hydrogen production plants and derivative commodity production facilities. Infrastructures for the storage, transport, distribution and delivery of hydrogen, and derivative commodities, are also considered in this category.

Institutional

Institutional enablers primarily encompass the policy measures that governments and regulators can use to support market development. These regulatory frameworks include, *inter alia*, import tariffs, taxation regimes and carbon pricing instruments, standards and certification, government support and procurement.

Social

The social enablers consider the additional considerations and potential benefits that trade in hydrogen derivative commodities may realise. Anticipated social benefits associated with developing these markets include sustainable industrialisation and growth, along with the associated job creation. Enabling measures in this area concern community engagement and other means of encouraging social acceptance of energy development, as well as skills development and wider educational measures to enable citizens to benefit from market growth.

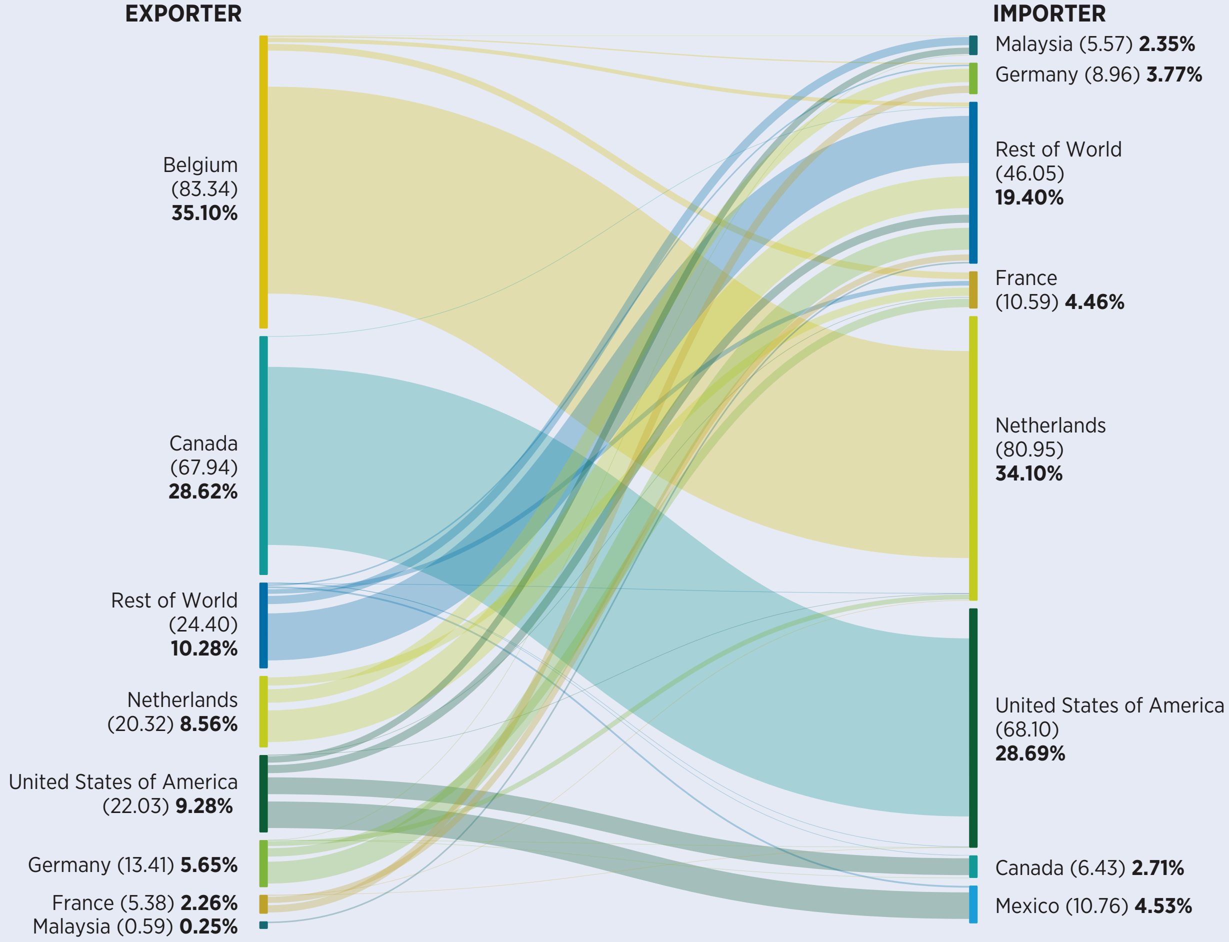
The following section introduces the current state of markets for hydrogen and hydrogen-derived commodities, *i.e.* ammonia, methanol and kerosene.

MARKET OVERVIEWS

HYDROGEN

Today, almost all hydrogen is produced from fossil fuels, emitting around 1.3 gigatonnes (Gt) of carbon dioxide equivalent (CO_2eq) emissions annually, posing a significant challenge for climate goals. To meet net-zero targets, low-carbon hydrogen production must expand five-fold by 2050, requiring large-scale deployment of electrolysers and renewable power. Costs remain a barrier, but falling prices for renewable electricity and anticipated reductions in electrolyser costs could make renewable hydrogen competitive with fossil-based alternatives by the 2030s, especially in regions with abundant renewable energy resources (IRENA, 2023a).

Figure 1 Bilateral trade patterns in hydrogen (HS 280410) in 2023, USD million and %



Source: WTO Analytical Database (WTO, 2024a).

Note: Based on bilateral import data; left-hand side indicates exporters, right-hand side indicates importing markets; RoW = rest of the world

HYDROGEN

Those regions with the best renewable energy conditions will likely become key renewable hydrogen producers due to lower production costs – provided they have an efficient access to capital, land and water. This geographic distribution could enable a more globally equitable energy landscape compared to that of fossil fuels, as renewable resources are distributed more widely globally, allowing various regions to participate in the future hydrogen economy. This offers a compelling opportunity for many economies.

Expanding renewable hydrogen production also has trade implications, as countries are expected to trade hydrogen itself or hydrogen-derived commodities like ammonia and methanol. Within the global energy transition, significant infrastructure investments, technology improvements and international cooperation will, however, be necessary to scale renewable hydrogen and meet rising demand.

Trade in hydrogen, regardless of its production method, exists only at a relatively small scale and occurs mainly between economies that are close to one another, reflecting the impact of high transport costs over longer distances and the still predominant use of natural-gas based hydrogen for ammonia production and petroleum refining – the main sources of current demand.[1]

Global imports of hydrogen amounted to USD 237 million in 2023, a decrease of more than 20% compared to the spike in hydrogen trade in 2022, but still significantly higher (37%) than the average of USD 174 million during 2012–2022 (IRENA *et al.*, 2023). Trends in the value of hydrogen trade are partly driven by fluctuations in the price of natural gas, which is the dominant source of current hydrogen production. More than 60% of the value of global trade in hydrogen took place between two neighbouring-country pairs in 2023, with Canada and Belgium exporting large volumes of hydrogen to the United States and the Netherlands, respectively (Figure 1). Diversification in these trade flows is expected in the coming years, as production projects are developed in a wider range of locations.

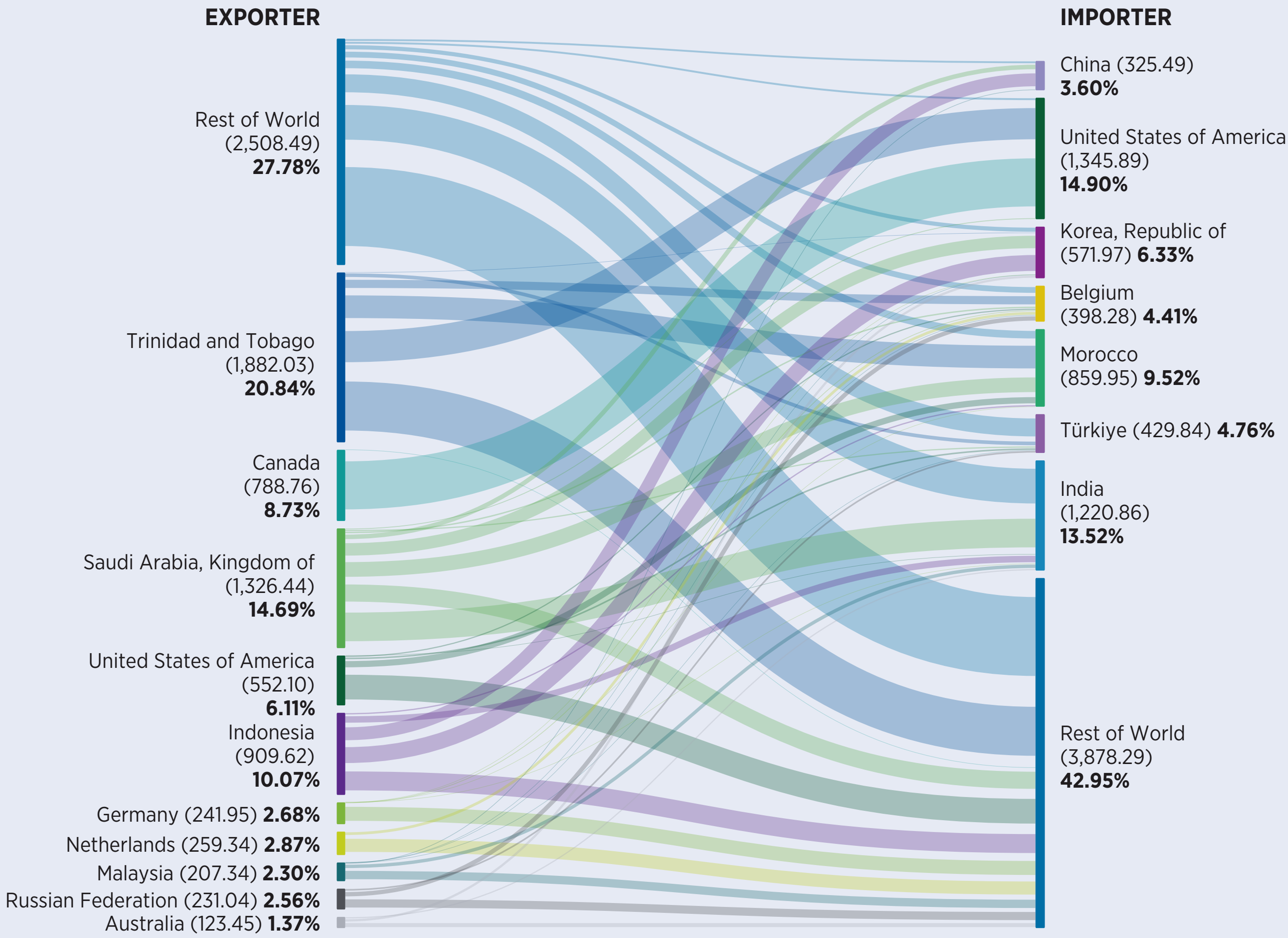
[1] *Trade statistics do not distinguish between trade in green hydrogen and fossil-fuel based hydrogen.*

MARKET OVERVIEWS

AMMONIA

Ammonia is an essential commodity, with 85% of its global production used for synthetic nitrogen fertilisers. Currently, ammonia production is responsible for around 0.5 gigatonnes (Gt) of CO_2eq annually, accounting for 1% of global carbon emissions. It is also the second-largest source of demand for hydrogen, with about 45% of global hydrogen demand used in ammonia production. Transitioning to renewable ammonia, produced from renewable hydrogen, presents a critical decarbonisation opportunity for the chemical industry. By 2050, the ammonia market could reach 688 Mt, driven by renewable ammonia used in agriculture, maritime fuels, and as a renewable hydrogen carrier (IRENA and AEA, 2022).

Figure 2 Bilateral trade patterns in ammonia (HS 281410) in 2023, USD million and %



Source: WTO Analytical Database (WTO, 2024a).

Note: Based on bilateral import data; left-hand side indicates exporters, right-hand side indicates importing markets.

AMMONIA

Ammonia production is currently highly reliant on fossil fuels, primarily natural gas and coal, making it an emissions-intensive process. Innovations in renewable hydrogen production and the scaling up of technologies such as electrolysis could reduce these emissions. Renewable ammonia, despite its high initial costs, could become cost-competitive by 2030 with the right policies, including carbon pricing and contracts for difference. The maritime sector, which is projected to require 197 Mt of ammonia by 2050, offers a significant opportunity for renewable ammonia, while international trade as a hydrogen carrier is expected to demand 127 Mt (IRENA *et al.*, 2022).

The current trade landscape for ammonia looks more diversified and less regionalised compared to hydrogen, reflecting its importance as a global commodity (IRENA *et al.*, 2023). Global imports in ammonia amounted to USD 9.0 billion in 2023, which is 38 times the value of hydrogen trade. Trinidad and Tobago and the Kingdom of Saudi Arabia are the main exporters of ammonia, while the United States, India and Morocco are the top three import markets (Figure 2). While trade of gaseous hydrogen itself is conducted mainly via pipelines, it is expected that renewable ammonia shipped by sea could represent as much as 45% of total trade in hydrogen by 2050 (IRENA *et al.*, 2023). Similar to hydrogen, opportunities exist for countries abundant in renewable energy to tap into renewable ammonia exports or produce renewable ammonia that could be used in their own existing fertiliser industry, or could spur the development of fertiliser production facilities.

Global efforts are already underway to build renewable ammonia production capacity, with major projects announced in countries at different stages of development such as Australia, Oman and Mauritania, with the latter being a least developed country (LDC). The first gigawatt-scale renewable ammonia plants are expected to begin operation in the coming years, primarily driven by solar and wind energy (IRENA *et al.*, 2022). By 2025, the technology and infrastructure to produce renewable ammonia at scale should be demonstrated, opening up new possibilities for its use in fuel cells, gas turbines, and maritime transport.

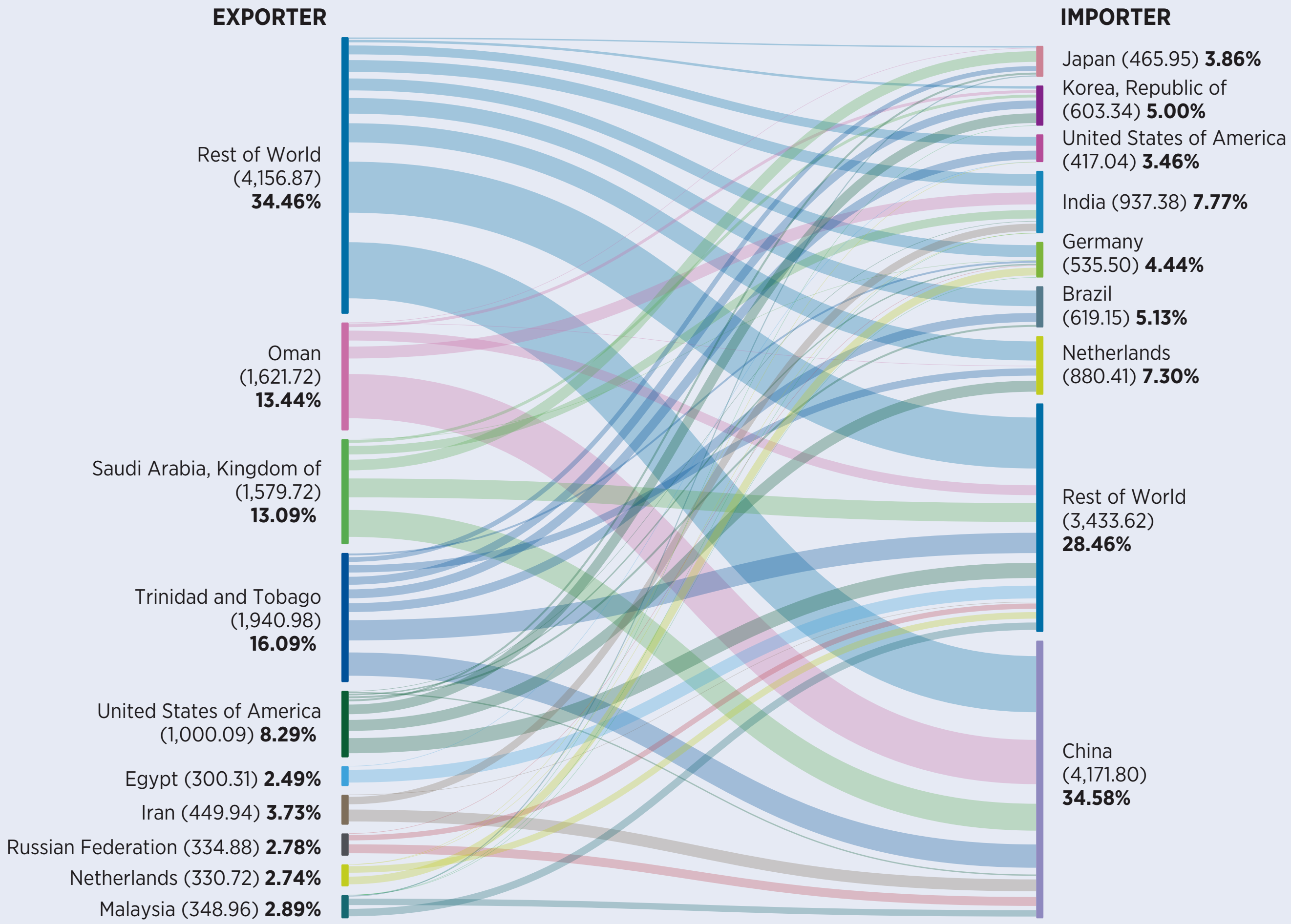
However, significant challenges remain, including the need for expanded shipping infrastructure, particularly for international ammonia transport, which currently stands at 18-20 Mt annually. Technological innovations and scaling up global electrolyser capacity – currently at just 2.1 GW per year – are crucial to meet the renewable ammonia production targets needed to achieve global climate goals by 2050 (IRENA, 2023a). Additionally, issues like nitrogen oxide emissions from burning ammonia must be addressed to ensure the sustainability of its use as a fuel (IRENA *et al.*, 2022).

MARKET OVERVIEWS

METHANOL

Methanol is a key product in the chemical industry, primarily used to produce other chemicals such as formaldehyde and plastics. Today, around 98 million tonnes of methanol are produced annually, almost entirely from fossil fuels, which contributes about 0.3 Gt of CO_2eq emissions per year. The production of renewable methanol, either as bio-methanol from biomass or green e-methanol from CO_2 and renewable hydrogen, is gaining interest for its potential to mitigate climate change. However, renewable methanol production is still in its early stages, with less than 0.2 Mt produced annually (IRENA and Methanol Institute, 2021).

Figure 3 Bilateral trade patterns in methanol (HS 290511) in 2023, USD million and %



Source: WTO Analytical Database (WTO, 2024a).

Note: Based on bilateral import data; left-hand side indicates exporters, right-hand side indicates importing markets.

METHANOL

Given the relative infancy of renewable methanol markets, global trade is dominated by fossil-fuel-based methanol. The value of global imports in methanol amounted to USD 12.1 billion in 2023 (Figure 3). The supply side of methanol is dominated by producers of natural gas, with Trinidad and Tobago, Oman, Saudi Arabia and the United States being the main exporters in 2023. The main market for methanol is China, which accounted for close to 35% of the value of global methanol imports in 2023. Other major importers of methanol are India, the Netherlands, Brazil and the Republic of Korea.

Renewable methanol offers a versatile and sustainable fuel option, compatible with existing distribution infrastructure and capable of reducing greenhouse gas (GHG) and other harmful emissions. Despite its promise, the higher cost of renewable methanol compared to fossil-based methanol remains a significant barrier to widespread adoption. However, with appropriate policy support, certification schemes, and scaling up of production technologies, renewable methanol could approach cost parity with fossil methanol in the future (IRENA *et al.*, 2021).

The production costs for bio-methanol are influenced by factors such as feedstock costs, investment and the efficiency of the conversion process used. Estimated costs currently range between USD 320 and USD 770 per tonne, though these could decrease with process improvements and co-production from industrial waste streams such as for black liquor from paper mills. Similarly, the cost of green e-methanol depends largely on the price of the CO_2 and hydrogen feedstocks used in its manufacture, with current production costs estimated at USD 800–1 600 per tonne, though they could fall to USD 250–630 per tonne by 2050 as renewable power and hydrogen production costs decline (IRENA *et al.*, 2021).

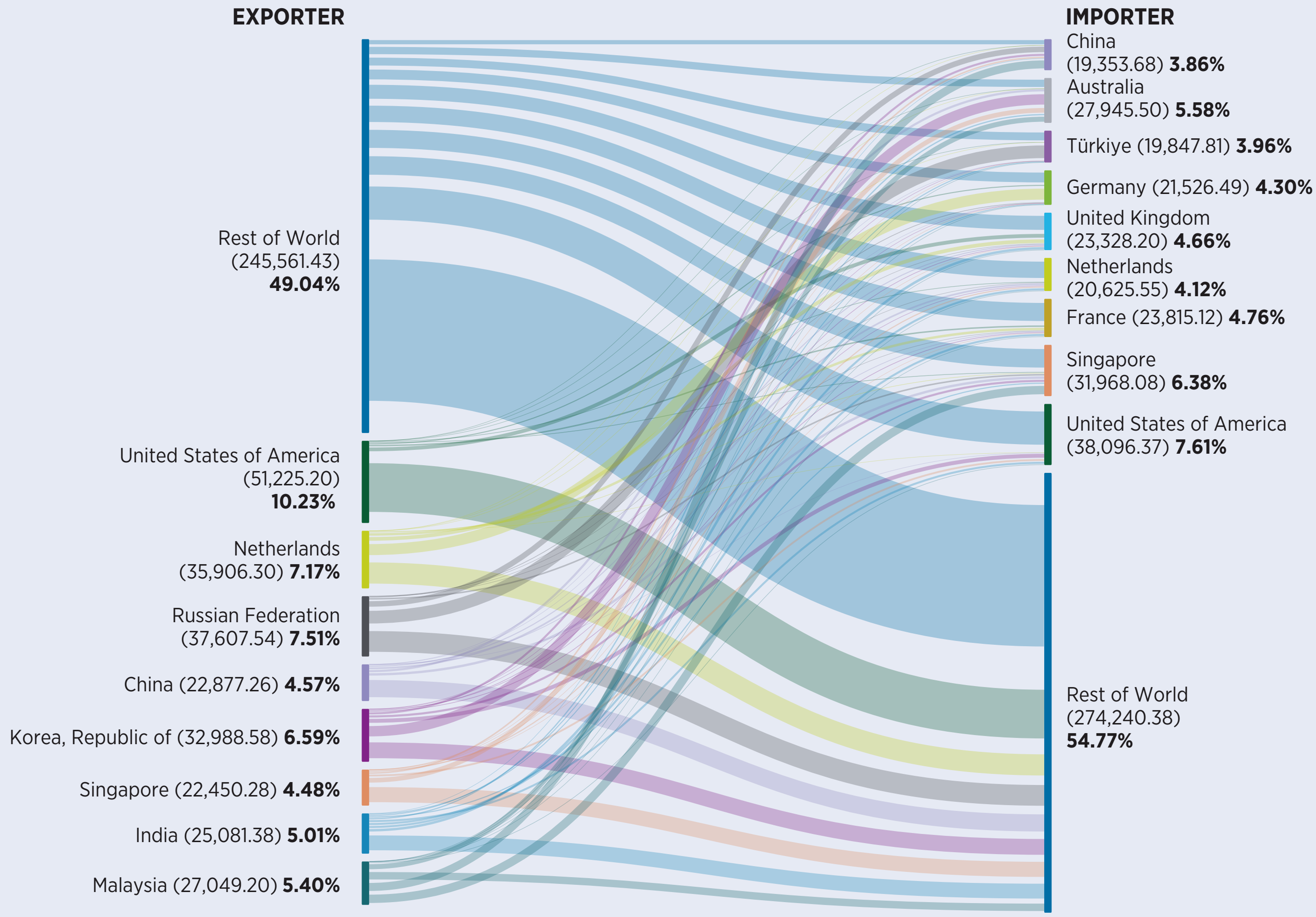
Ultimately, renewable methanol has the potential to play a key role in decarbonising the chemical industry and hard-to-abate sectors like road and maritime transport, but it will require significant investment, innovation and policy intervention to become competitive with fossil fuels.

MARKET OVERVIEWS

KEROSENE

Kerosene is a hydrocarbon fuel that is used in a number of sectors, but is a particularly important component of jet fuel. E-kerosene, which is synthetic kerosene produced using renewable hydrogen and a source of carbon (derived from CO_2), is considered to be another prime candidate for the decarbonisation of hard-to-electrify sectors, especially international aviation (IRENA, 2023a). Chemically, e-kerosene is the same commodity as hydrocarbon-derived kerosene, and so one of the attractive features of its future use as an alternative fuel is its capacity to act as a "drop in" replacement, sharing common infrastructure currently used to distribute and dispense conventional kerosene.

Figure 4 Bilateral trade patterns in kerosene (HS 271019) in 2023, USD million and %



Source: WTO Analytical Database (WTO, 2024a).
Note: Based on bilateral import data; left-hand side indicates exporters, right-hand side indicates importing markets.

KEROSENE

Global imports in kerosene amounted to more than USD 500 billion in 2023 (Figure 4). Kerosene use as a jet fuel explains the immense magnitude in trade; the value of global kerosene trade in 2023 was more than 41 times that of trade in methanol, and more than 55 times that of trade in ammonia. Compared to other hydrogen derivatives, supply is less concentrated on the export side, with the top five suppliers – the United States, Russia, the Netherlands, the Republic of Korea and Malaysia – representing around 37% of the value of global imports. The United States, Singapore, Australia, France and the United Kingdom were the top five import markets in 2023.

ENABLERS

PHYSICAL

The physical infrastructural enablers required to scale up international markets for renewable hydrogen and renewable ammonia, methanol and kerosene cut across the full value chain. This infrastructure is needed to produce the commodities, store and distribute them to users, and to facilitate end use at demand sites.

HOLISTIC CONSIDERATION OF RESOURCE AVAILABILITIES AND REQUIREMENTS FOR INFRASTRUCTURE DEVELOPMENT PLANNING

Inputs of renewable electricity and water are needed in the production pathways of all of the commodities considered here, and a sustainable source of carbon is also essential for the production of methanol and kerosene. Developing markets for renewable hydrogen and renewable hydrogen-derived commodities naturally require the deployment of electrolytic hydrogen production capacity, and the associated renewable power generation capacity that is needed to provide input power. The infrastructure requirement for renewable power inputs, across the full value chain, will therefore necessitate the deployment of further renewable generation capacity and associated power network extension and development. Building up value chains for the derivative commodities will also require investments in plant facilities that can convert renewable hydrogen and other feedstocks into ammonia, methanol and e-kerosene, as discussed in the market descriptions, respectively. All of these parameters should be considered within long term energy scenarios (LTES) and energy system planning, to ensure coherence. More generally, working towards establishing a circular water economy and developing water-efficient clean energy solutions is crucial to ensure sustainable use of scarce water resources (Global Commission on the Economics of Water, 2024).

Hydrogen

Electrolysis is the splitting of water, using electricity, to produce hydrogen and oxygen. As such, water is an essential feedstock for the process. In many regions, water constraints are a key challenge for the development of renewable hydrogen and hydrogen-derived commodity value chains (IRENA and Bluerisk, 2023). As many of the regions in which renewable resources are most concentrated are also locations with arid climates, this challenge is particularly acute (IRENA, 2024b). One means of resolving this challenge is a clear strategy for the development of water infrastructure alongside production facilities for renewable hydrogen and hydrogen-derived commodities. Some industrial cluster projects are being developed in which a shared, over-sized desalination facility is planned, with the intention of addressing both local industrial water needs and those of the hydrogen producer, while also enabling enhanced water supply for adjacent communities (UNIDO, 2023a).

Derivative commodities

Another crucial material feedstock for the production of derivative commodities – specifically methanol and e-kerosene – is a source of carbon, usually in the form of CO_2. Carbon can be derived from biogenic sources, or captured either from sources of industrial emissions (via carbon capture and utilisation) or from the air (via direct air capture). The availability of biogenic carbon is likely to be limited in most geographies and markets, and carbon capture technologies are not yet well developed. A strategy for sourcing input carbon is therefore an essential priority for developing methanol and e-kerosene value chains (Uddin and Wang, 2024).

PRIORITISING DISTRIBUTION INFRASTRUCTURE DEVELOPMENT TO ENSURE MARKET ACCESS FOR PRODUCERS

The potential to transport hydrogen via repurposed natural gas pipelines has been discussed for a number of years. There are technical challenges associated with this potential repurposing, as some pipeline materials are not compatible with hydrogen. Research is underway on these issues, with scientists, engineers and pipeline operators working together to identify technical and operational solutions (ENTSOG *et al.*, n.d.), which will need to be implemented if this pathway is to become viable at scale. Kerosene is also transported via pipeline today, and e-kerosene can be handled in the same manner. Meanwhile, ammonia and methanol are typically transported via ship and further port infrastructure will be required as the markets for these commodities scale up. For all of these commodities, storage infrastructure will need to be developed. There are substantial financial challenges associated with the development of infrastructures across transport, safe storage and distribution systems, which will likely require government intervention and international cooperation.

Box 1

CASE STUDY **Preparing for ammonia imports in the Republic of Korea**

The Ministry of Trade, Industry and Energy in the Republic of Korea has been working with domestic and international partners to consider the infrastructure requirements for the importation of large volumes of low-emission ammonia in the future. The Government of the Republic of Korea outlined a full roadmap for the hydrogen sector in 2022, with a focus on industrial sectors. Focus in the country has increasingly been placed on the role for ammonia, in particular, both in the chemicals and industrial sectors, and as a potential fuel for co-firing alongside fossil fuels in the power sector. The Ministry is aiming to facilitate imports of ammonia to ensure security of supply, and is therefore currently planning the development of large-scale port and terminal facilities to handle the delivery of ammonia by ship from exporting markets. The Republic of Korea is collaborating with Japan, as another potential importer of ammonia, to develop technological solutions to handle and store ammonia, as well as the market frameworks required to facilitate the operation of these facilities. The Republic of Korea has also signed agreements with numerous potential exporters including Australia, Saudi Arabia and the United Arab Emirates.

Sources: (Ammonia Energy Association, 2024; Argus Media, 2022; Ministry of Trade, Industry and Energy of the Republic of Korea, 2023a, 2023b, 2025).

SUPPORTING THE DEVELOPMENT OF DIVERSIFIED SUPPLY CHAINS ACROSS SECTORS

It is crucial that equipment and infrastructure are developed to facilitate the eventual use of hydrogen-derived commodities in the hard-to-abate sectors for which they offer decarbonisation solutions. In heavy-duty transport sectors – especially shipping and aviation – refuelling systems will need to be developed to enable the dispensing of ammonia, methanol and e-kerosene as needed. This infrastructure may be repurposed from current systems, and in the aviation context this is a particularly viable for e-kerosene, as a “drop in” alternative fuel. For ammonia and methanol, new technologies and systems will need to be developed to manage the use of these fuels in new applications, and financial support may be required to enable the development of the associated supply chains. Further supply chain development is needed in the components and systems which will be used to react or combust ammonia and methanol to release energy, in their use as fuels.

INSTITUTIONAL

ALIGNING STANDARDS AND REDUCING DIVERGENCES IN CERTIFICATION TO ENSURE CREDIBLE GLOBAL MARKETS

International standards and certification are crucial for establishing credible and transparent markets for renewable hydrogen and the derivative commodities. They provide a consistent framework for measuring and verifying the environmental integrity of hydrogen production, ensuring that it meets specific emissions thresholds. Standards can facilitate trade by creating a common understanding of what qualifies as renewable hydrogen, both now and in the future, while certification, verification and other conformity assessment procedures, can reduce information asymmetries and ensure transparency (IRENA, 2023b).

The proliferation of different standards leads to unpredictability for producers, increasing transaction costs and reduced effectiveness of carbon emission reduction efforts. As with other sectors, convergence or common understandings across countries on carbon measurement and verification approaches are needed, in order to avoid trade disruptions and foster global decarbonisation efforts (WTO, 2022).

Hydrogen

Governments and businesses are increasingly developing their own sustainability standards and certification schemes for hydrogen that differ in design and implementation (Gale *et al.*, 2024). Most mechanisms are designed for a specific economy or region, but others are working towards being recognised internationally (*e.g.* the Green Hydrogen Standard, CertifHy and the Zero Carbon Certification Scheme) (IRENA, 2023b).

With respect to emissions accounting, one example is a technical specification developed by the International Organization for Standardization (ISO) and launched as part of the COP28 Presidential Action Agenda on Hydrogen. It presents a methodology for determining the GHG emissions associated with the production, conditioning and transport of hydrogen to point of consumption (ISO, 2023). Currently being converted into a set of standards, this methodology aims to promote comparability across regulatory frameworks and certification systems.

Countries across geographies have been pursuing different approaches to hydrogen classification and identifying different emissions thresholds for hydrogen; these are reflected in national regulations and certification schemes. There is currently no global framework that provides guidance on the definition of clean, renewable, sustainable, green or low-emission hydrogen. The differing criteria and scope of methodologies used at the national level, such as on eligible hydrogen production pathways, risk creating hurdles for project developers. Navigating separate compliance and certification processes for each country or customer to access subsidies or market premiums results in higher transaction costs and may restrict international trade in renewable and low-emission hydrogen, ultimately hindering the growth of a global market (Hydrogen Council *et al.*, 2024; IRENA, 2024c).[2]

[2] *Emission intensity levels for hydrogen production under "well-to-gate" boundaries differ widely across regulations and certification systems. For example, the US Clean Hydrogen Production Tax Credit sets a low limit of 0.45 kgCO_2eq/kgH_2, while China's Hydrogen Alliance standard allows up to 14.5 kg CO_2eq/kgH_2. "Well-to-point-of-use" regulations also vary by production method.*

There is therefore a need for continuous cooperation among governments and stakeholders with the aim to align technical criteria, including those used to classify hydrogen as green or low carbon. Even though differences may legitimately reflect national or regional specificities, increased coordination and interoperability would be beneficial in providing certainty as to the characteristics of hydrogen production exporters should focus on and will give a clear investment signal for the efficient deployment of renewable hydrogen infrastructure (IRENA, 2020). A declaration of intent was signed by nearly 40 economies at COP28 seeking to work towards – and accelerate development of technical solutions enabling – the mutual recognition of their certification schemes (COP28, 2023).

In many developing economies, it is also necessary to build the technical capacity of national quality infrastructure and conformity assessment systems to verify compliance with international hydrogen standards. Support from governments and industries through capacity building and technical assistance could expedite the development and approval of standards for hydrogen deployment (IEA *et al.*, 2023).

Derivative commodities

Renewable hydrogen derivatives, such as ammonia and methanol, are increasingly understood as a priority for global trade, as they offer easier shipment options over long distances. This increases the need for standards and certification schemes to verify their environmental attributes. Regulatory frameworks are evolving to establish acceptable emission levels for these products. Recent analysis, however, shows that, while regulations, standards and certification schemes for hydrogen are advancing, those for derivatives lag behind (IRENA, 2024c). There is an opportunity for global multi-sectoral cooperation to ensure that emerging standards and certification schemes for derivates are interoperable and enable comparison and transparency across hydrogen derivatives, taking into account the varied sector uses of each derivative.

Each of the derivative commodities discussed will find applications in different end uses and contexts; as such, distinct standards and certification mechanisms for each commodity will likely need to be developed.

An internationally recognised certification system for renewable ammonia is vital due to its varied uses and complex production processes. Such a system must account for different ammonia uses, be they chemical feedstock, fuel or energy storage; align with international standards to facilitate collection and presentation of data; and ensure transparency. Current schemes, albeit limited in number, vary in scope, emission thresholds and accounting methodologies. A robust, interoperable framework would advance the renewable ammonia market by providing a common understanding of what "green" or "renewable" ammonia denotes, and supporting other policies like procurement policies and carbon pricing (IRENA, 2024c).

Renewable methanol's diverse applications also require a harmonised and flexible emission accounting system to ensure consistent environmental impact measurement and avoid inefficiencies from conflicting standards. For instance, if methanol is used as shipping fuel, regulatory cooperation, including establishing guarantees of origin and precise GHG emissions measurements, would be crucial to prevent ships from bypassing stringent regulations by registering under more lenient flags (IRENA, 2020). As for ammonia, a modular and interoperable framework would allow for transparency and integration of emissions data into sustainability strategies. A key challenge in certifying renewable methanol is ensuring the carbon used in its production comes from sustainable sources like biogenic materials (*e.g.* biomass) or captured from existing emissions (such as through direct air capture or carbon capture and utilisation), rather than from fossil fuels.

To ensure its sustainability and reduce barriers to its adoption, e-kerosene would likely benefit from inclusion in standards and certification schemes that exist or are in development for other sustainable aviation fuels (SAFs). Alternatively, bespoke standardisation and certification arrangements for e-kerosene could be made interoperable with those developed for other SAFs to avoid market fragmentation. The carbon offset and reduction scheme for international aviation (CORSIA) – a global market-based emissions reduction system – allows aircraft operators to reduce their offset requirements by using alternative fuels that meet certain eligibility criteria. Relevant standards are defined in the Convention on International Civil Aviation. The roundtable on sustainable biomass initiative (RSB) is also an international fuel certification system used by biomass and fuel producers, as well as traders, processors and transporters (Wang *et al.*, 2024).

CALIBRATING GOVERNMENT SUPPORT AND PROCUREMENT TO FACILITATE DEMAND AND OFFTAKE

Government support and green procurement strategies are complementary tools for harnessing the renewable hydrogen and derivatives markets. Subsidies lower investment risks for producers by reducing the high initial costs of production, while green government procurement ensures stable demand for sustainable products, driving market development and creating long-term incentives for producers to invest in green technology, foster technological advancements, and scale production, making renewable hydrogen more competitive.

Tax regimes play a pivotal role in promoting the development of renewable hydrogen and derivatives. In contrast to environmental taxes that penalise carbon-intensive industries, tax incentives such as credits for renewable energy investments or exemptions on renewable hydrogen production equipment can reduce costs and promote innovation. For example, providing reduced corporate income tax, value-added tax exemptions, or tax credits for investments in electrolysers can lower initial capital requirements for hydrogen producers, making renewable hydrogen more attractive (Köppl and Schratzenstaller-Altzinger, 2021).

Aligning green procurement strategies with international trade rules, such as the WTO Agreement on Government Procurement, would ensure transparency, non-discrimination and fair competition. This could foster innovation, support international participation and help scale the global renewable hydrogen market efficiently.

Hydrogen

Beyond direct financial support, governments are increasingly adopting policies that create long-term demand for renewable hydrogen. For example, demand-side targets and quotas that can signal future market demand and encourage capacity expansion. Support for research and development (R&D) is essential to reducing production and transportation costs, especially for initiatives focusing on improving components and systems for critical technologies such as electrolysers. The cost gap between renewable and fossil fuel-based hydrogen can also be narrowed by introducing price premiums for renewable hydrogen, recognising its environmental value (IRENA, 2020).

Green hydrogen projects are capital-intensive as they require a significant upfront investment in infrastructure, equipment and construction. Governments can boost their renewable hydrogen sector's competitiveness by implementing supportive fiscal policies that reduce initial investment costs, such as offering competitive land prices in industrial zones, flexible leasing options and assistance with land development. Fiscal measures like investment deductions and capital allowances can also be considered, ensuring they are balanced with responsible fiscal management. These incentives could extend to electrolysers and renewable technologies crucial for renewable hydrogen production, such as solar and hydro power technologies (Africa Green Hydrogen Alliance, 2024). At the same time, this type of support measures may be hard to implement for many developing economies with constrained fiscal space.

Moving away from a volume-based tax system towards taxation based on fuels' energy content and CO_2eq emissions could be another important policy change aimed at stimulating investment and corresponding off-take of low carbon and net carbon neutral fuels through a technology-neutral approach (Methanol Institute, 2020).

Renewable hydrogen market development requires stable prices and investor confidence. Government tenders are in wide use for wind and solar photovoltaic (PV) equipment, and are increasingly being used for renewable hydrogen, offering transparency and price discovery (Renewables Now (REN21), n.d.). Mechanisms such as Contracts for Difference (CCfDs) and auction systems are designed to ensure renewable hydrogen can compete with cheaper, fossil fuel-based hydrogen. Advance market commitments could also guarantee contractual agreements for future purchases of renewable hydrogen and derivatives. These instruments help bridge the price gap, de-risking investments and providing a predictable revenue stream for producers, even in the face of market fluctuations. These kinds of tools help encourage long-term investments in renewable hydrogen projects, fostering a stable and scalable market (IRENA, 2020).

Economies can improve the investor appeal of renewable hydrogen projects by adopting different strategies to lower capital borrowing costs and derisk investments. These include: providing government-backed interest rate subsidies or guarantees; establishing credit enhancement programmes with government or institutional guarantees to reduce lender risks; collaborating with development finance institutions to access concessional loans or tailored financing; and fostering public-private partnerships to share financing risks and costs. These efforts aim to create a conducive investment environment, enhance project feasibility, and accelerate the shift towards sustainable energy solutions (Africa Green Hydrogen Alliance, 2024).

Derivative commodities

Ammonia is a hazardous chemical that is taxed in many jurisdictions due to its environmental impact, particularly when used in agriculture as fertiliser. It can release nitrogen compounds like nitrous oxide (a potent greenhouse gas) and nitrates that cause water pollution, harming ecosystems (EEA, 2019). Regulating the harmful ecosystem effects of renewable ammonia production therefore remains essential.

To encourage greener shipping practices, fiscal incentives such as lower tonnage taxes for cargo ships with reduced GHG emissions have been implemented. Additionally, several of the world's largest ports adjust their fees based on ships' environmental impacts, with some specifically accounting for GHG emissions. Other strategies could include a fixed levy on all ships based on fossil fuel consumption or integrating shipping into emissions trading systems. These financial incentives aim to make green alternatives, such as ammonia and methanol, more economically viable compared to fossil fuels (IRENA, 2020).

Incentives, such as producer or blender tax credits – the latter incentivising companies to blend biofuels with fossil fuels – have played a significant role in encouraging investment and the development of conventional biofuels, like bioethanol and biodiesel. Despite the higher capital investment costs of e-kerosene, its production may still benefit from these types of incentive. Specifically, loan guarantees and grants could play an important role in encouraging initial investment in production facilities and producer incentives could mitigate longer-term risk for investors (IRENA, 2021).

Many developing economies provide support for the acquisition of nitrogen fertilisers to enhance agricultural productivity (Malpass, 2022). Governments could refine policies by focusing subsidies on supporting renewable ammonia instead. Support measures often aim to narrow the price gap with cheaper fossil fuel alternatives. To promote the uptake of sustainable marine fuels – and renewable methanol in particular – governments are also providing financial incentives, tax breaks, and research funding (Keating, 2024).

To reduce the cost gap between fossil fuels and renewable fuels, financial incentives could be implemented, such as repurposing fossil fuel subsidies, offering grants for renewable fuel production and extending emissions trading systems to aviation. Since renewable fuels may not achieve cost parity with fossil fuels in the near term, blending mandates could serve as an interim solution to support their market adoption (IRENA, 2020).

REBALANCING TARIFFS FOR KEY PRODUCTS AND SERVICES TO REDUCE TECHNOLOGY COSTS

Reviewing and rebalancing import tariffs along the renewable hydrogen and derivatives value chains can drive the development of sustainable energy systems. Currently, all these products fall under the same customs classification, whether produced using fossil fuels or renewable energy, with no distinction in import duties. The commodity categories in the World Customs Organization's Harmonized System (WCO HS) are not traditionally based on process and production methods. However, as the markets for renewable hydrogen develop, separate tariff classifications could be envisaged either at the HS 6-digit level or at the national level, which is often more disaggregated. Coordination in implementing such national classifications could allow governments to increase transparency, monitor international trade in these products and implement more effective trade measures. In turn, reviewing tariffs for renewable hydrogen and its derived commodities could incentivise sustainable production.[3]

Figure 5 shows average most-favoured-nation (MFN) applied and bound tariff rates for hydrogen and derivatives by country income group. Average applied tariffs are highest for kerosene at 7.7%, compared to average tariff rates of 5% for hydrogen, 4.5% for ammonia and 4.4% for methanol. For all four commodities, average applied tariffs are lowest in high-income economies, ranging from 3.5% for hydrogen to 4.1% for kerosene. Applied tariffs in other income groups tend to be 1-2% higher – the exception being kerosene, for which average tariffs are significantly higher in low-income economies (8.8%) and lower-middle-income economies (13.0%).

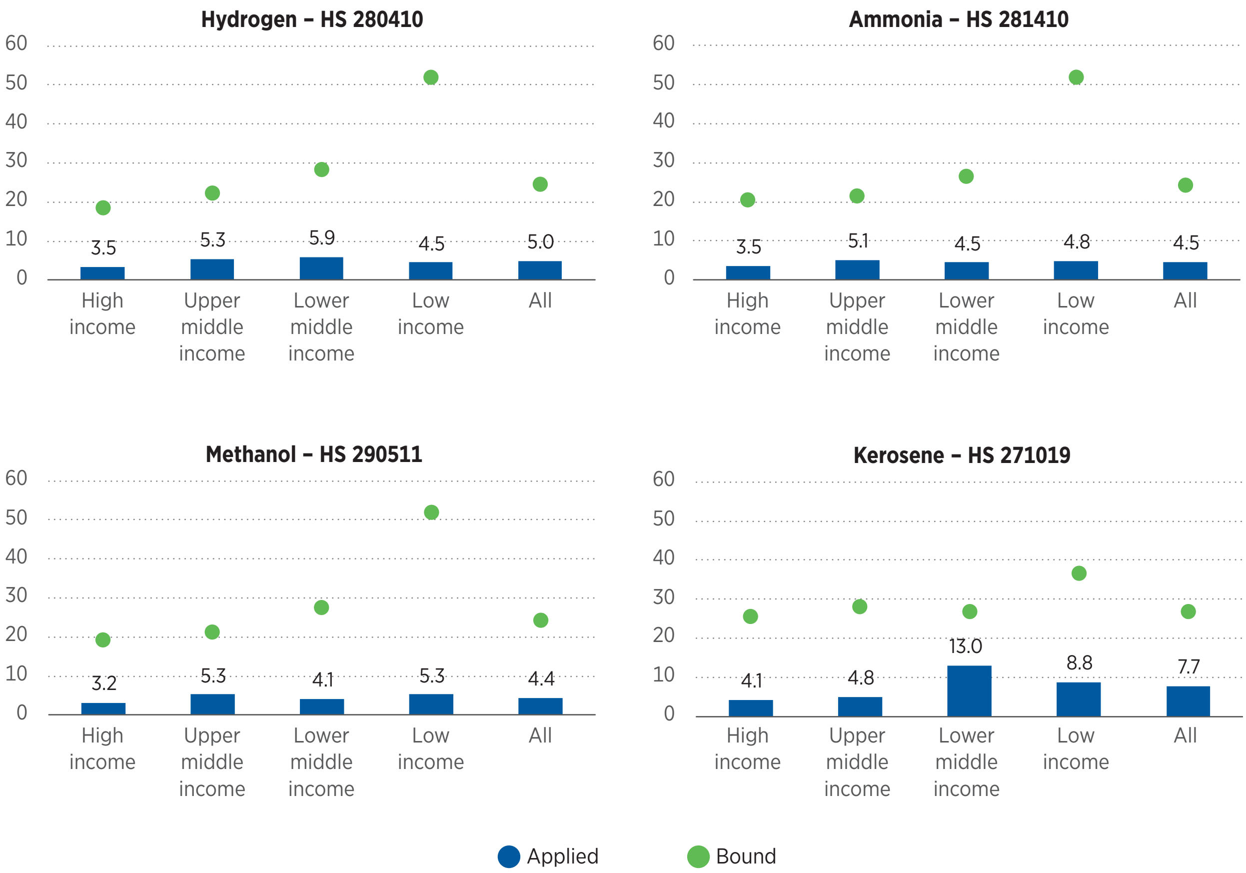
Figure 5 also provides information on bound tariff rates, which are included in WTO members' schedules of concessions and represent ceiling rates beyond which members have committed to not increase their tariffs. High-income economies tend to have bound rates that are relatively close to actually applied tariff rates, which provides more predictability to traders. Low-income economies tend to have a bigger gap between applied and bound rates, which may give them more flexibility to adapt the applied rate in line with their policy priorities at the expense of less predictability, which can undermine investment in the long run.

Bound duties can be reduced autonomously by any WTO member, or in a coordinated manner by a group of members, which has been done in the past with the 1996 Information Technology Agreement (ITA) and the 2015 ITA Expansion. Thus, there is scope to permanently reduce or eliminate the gap between the bound and applied tariffs, either individually or through international cooperation, thereby providing long-term stability and security to investors in these areas.

The implementation of the WTO Trade Facilitation Agreement (TFA) can also enhance renewable hydrogen trade by simplifying customs procedures, increasing transparency and harmonising documentation requirements, thus reducing costs and delays for cross-border shipments. Governments could align trade facilitation with wider climate action policy plans and adopt green customs procedures, such as electronic documentation, harmonising inspections and expedited conformity assessment procedures, and facilitating the implementation of low-carbon freight transport and more carbon-efficient routes and logistics systems (WTO, 2023a).

[3] *The WCO has already considered how to green the HS, in order to support environmentally sustainable trade. See: (WCO, 2023). However, the process may take a number of years to be fully implemented.*

Figure 5 Average tariffs for hydrogen and derivatives by income group



Source: WTO Integrated Database and WTO Consolidated Tariff Schedules (CTS) Database (WTO, 2024a).

Notes: Average applied (bound) tariffs are based on 32 (28) high-income economies, 47 (35) upper middle-income economies, 45 (28) lower middle-income economies and 20 (9) low-income economies. Since not all WTO members have bound their tariffs for all products, the number of observations for bound tariffs is lower compared to applied tariffs.

Lowering tariffs and other barriers on environmental goods and services can be an efficient and cost-effective strategy to deploy environmental technologies (Steenblik, 2020). Import duties on some critical components along the renewable hydrogen value chain such as electrolysers, compressors and fuel cells tend to be significant (IRENA *et al.*, 2023). Reducing tariffs on renewable energy equipment by even a relatively small number of percentage points could make an important contribution to reducing renewable energy costs and increasing the uptake of low-carbon technologies (WTO, 2023a). This impact could be particularly strong in larger markets where demand for such technologies is substantial.

The Trade and Environmental Sustainability Structure Discussions (TESSD), an initiative by a sub-group of WTO members,[4] recently produced an analytical summary that highlights renewable energy goods and services, including in the renewable hydrogen sector (WTO, 2024b). The summary provides for opportunities and approaches for governments to reform their tariff policies and facilitate the expansion of renewable hydrogen trade. Future amendments to the WCO HS could also consider assigning separate subheadings to hydrogen equipment, such as electrolysers and fuel cells, to facilitate tariff reduction and elimination.[5]

[4] *See (WTO, n.d.).*

[5] *For instance, currently electrolysers are included under Harmonized System (HS) subheading 854330: Machines and apparatus for electroplating, electrolysis or electrophoresis.*

CO-ORDINATING CARBON PRICING MECHANISMS TO ENHANCE COMPETITIVENESS

Environmental taxes and carbon pricing mechanisms are considered by many as a key policy option available for tackling climate change, as they send a clear economic signal to emitters. Carbon pricing can incentivise shifts in consumption and investment patterns and result in lower emissions (WTO, 2022). It can also enable economies to specialise according to their revealed comparative advantage in producing low-carbon goods, contributing to climate change mitigation (WTO, 2023a).

While carbon pricing remains most common in power and industry, governments are increasingly exploring it in other sectors, such as maritime transport (World Bank, 2024). These mechanisms may provide an incentive to switch to renewable alternatives – hydrogen, ammonia, methanol or kerosene – provided the carbon tax is appropriately priced.

Hydrogen

Hydrogen can be subject to carbon pricing based on its emissions intensity. Several carbon pricing instruments cover hydrogen, and the European Union (EU) Carbon Border Adjustment Mechanism (CBAM) affects the hydrogen sector by putting a price on emissions associated with hydrogen produced in countries outside the EU, with the goal of encouraging sustainable practices and reducing carbon footprint (European Union, 2023).

Derivative commodities

Ammonia production is covered under carbon pricing instruments as part of broader mechanisms that target industrial emissions or fossil fuel use. Renewable ammonia is not currently price competitive when compared with ammonia from fossil fuels. A carbon price of around USD 150 per tonne of CO_2 paid by manufacturers using fossil fuels would help level the playing field and make renewable ammonia more competitive with existing fossil-based ammonia production (IRENA *et al.*, 2022). Similar considerations apply to methanol, as a fuel that can fall within the scope of actions to promote cleaner, low-carbon fuels by measuring their carbon intensity (IRENA *et al.*, 2021). E-kerosene, as a renewable fuel, could be factored into transport sector decarbonisation targets and could be given additional weight due to its higher costs (IRENA, 2020).

HARNESSING INTERNATIONAL COOPERATION TO ENSURE EQUITABLE GROWTH

A lack of coordination in environmental policies, such as carbon pricing and subsidies, can lead to inefficiencies and higher transaction costs. Uncoordinated approaches may lead to a patchwork of regulations and mixed market signals, breeding uncertainty and reducing overall effectiveness in addressing environmental challenges. This misalignment can also negatively impact trading partners. Unilateral policies risk triggering retaliatory actions, potentially causing trade conflicts and undermining the success of global environmental initiatives (WTO, 2023b).

For instance, carbon pricing policies are fragmented, with over 70 different schemes already in place globally that cover some 23% of total emissions. Carbon prices vary widely across the globe, from less than USD 1 to more than USD 130 per tonne of CO_2eq emitted (World Bank Group, n.d.). International cooperation on trade and carbon pricing is crucial to prevent trade tensions. Discussions within the WTO and other platforms can enhance transparency and offer opportunities for feedback on upcoming carbon pricing policies (WTO, 2022).

A coordinated approach to environmental sustainability of hydrogen and hydrogen-derived commodities is essential to ensure equitable economic growth. If governments work towards aligning their climate policies on renewable hydrogen and derivatives, the cost of climate change will be internalised in the prices of goods and services allowing economies with clean energy to realise their competitive advantage in energy-intensive industries (WTO, 2023b). International cooperation can ease the economic shifts caused by hydrogen technology adoption.

Acknowledging regional differences in national strategies and promoting international dialogue can address and resolve potential conflicts, facilitating a smoother transition in the hydrogen sector (Deloitte, 2023). In June 2023, at the Clean Energy Ministerial in Goa, governments launched the International Hydrogen Trade Forum (IHTF), which represents a high-level platform for dialogue between potential exporters and importers of hydrogen and its derivatives, coordinated by the United Nations Industrial Development Organization (UNIDO) (UNIDO, 2023b).

In addition, coordinated support for clean technology R&D can foster global technological diffusion. Positive spillovers from green innovation worldwide could allow developing economies with absorption capacity to adopt clean technologies more rapidly (WTO, 2023b). Scaling up the hydrogen market requires reducing costs and industrialising current technologies, as well as developing and enhancing systems for long-distance hydrogen transport, conversion and reconversion processes (Deloitte, 2023). These themes feature in IRENA's Collaborative Framework on Renewable Hydrogen, which provides the Agency's Members with an opportunity to discuss progress in developing renewable hydrogen and derivative value chains (IRENA, 2024d).

Global alliances are crucial for sharing know-how and best practices, and establishing local hydrogen value chains to accelerate the development of international hydrogen markets. Such collaboration could ensure comprehensive knowledge transfer and successful integration of new technologies into global markets (AFID, n.d.; Deloitte, 2023).

Some economies, like Chile, have deployed a broad set of trade policies to support the development of renewable hydrogen and derivatives (see Box 2). These measures could be considered as examples for other economies to consider.

Box 2

CASE STUDY Applications of institutional enablers in Chile

- **Emission Trading System**: The government is set to introduce a cap-and-trade system aimed at boosting hydrogen demand in key industries. The system will include a pilot program to support hydrogen-based technologies for decarbonising high-emission sectors.
- **Taxes**: The government plans to offer tax incentives for companies investing in decarbonisation technologies, including electromobility, renewable energy and green hydrogen. The reforms will also lower the corporate income tax rate and enhance tax credits for R&D.
- **International certification**: A new sustainability certification system is being developed to align with international standards and cater to the requirements of key import markets. In parallel, the National Renewable Energy Registry will be enhanced to support hydrogen certification and ensure the system's compliance with global norms.
- **Electrolyser subsidies**: The government is offering subsidies of up to USD 10 million to incentivise the construction of electrolyser factories. This initiative invites companies to apply for financial assistance, fostering the growth of hydrogen production infrastructure.
- **Investment incentives**: To attract private investment, the government is promoting financial instruments designed to mitigate risk and lower costs for green hydrogen projects. These measures aim to provide positive market signals, accelerating investment and development within the industry.
- **Support for SMEs**: The Green Hydrogen Accelerator program co-finances small and medium-sized green hydrogen projects with electrolysers under 500 kW capacity. With two new projects awarded in the third version of the accelerator, this initiative supports local industry decarbonisation by providing financial assistance to smaller-scale projects.
- **Allocation of state-owned lands**: Under the "Ventana al Futuro" program, the government allocates state-owned lands for green hydrogen production facilities. The 2023–2030 action plan prioritises finalising land assignments from the programme's initial phase and launching a second phase in 2025 to release additional land for new projects.
- **Demonstration application**: As part of its National Hydrogen Strategy, the government plans to introduce hydrogen-powered buses into the public transportation network by 2025. This pilot will assess the technical and economic feasibility of using hydrogen in public transport.
- **Maritime corridors**: Chile aims to develop green maritime corridors, promoting decarbonised shipping routes using low-emission fuels like ammonia. By 2030, the country plans to establish the first commercial green maritime corridor in Latin America.

Sources: (Government of Chile, 2024; Hunton Andrews Kurth, 2024; ISA, n.d.).

SOCIAL

The emergent renewable hydrogen sector offers economic and sustainable development opportunities. Many developing economies see new possibilities in participating and profiting from the global energy market, as they have high renewable energy potential and could potentially produce renewable hydrogen and its derivatives at low cost. Future renewable hydrogen and derivatives demand hubs – such as the European Union, Japan and the Republic of Korea – see these commodities as an opportunity to decarbonise their industries while maintaining industrial competitiveness and enhancing energy security. This section explores the anticipated social benefits associated with the development of the renewable hydrogen and derivative markets, including sustainable industrial development and job creation. It also looks into enabling measures such as community engagement and skill development.

The production of renewable hydrogen and its derivatives, especially in large-scale projects, requires access to green electricity and water, as well as available land. As discussed above, these projects also necessitate extensive infrastructure and, if existing infrastructure cannot be repurposed or retrofitted, new infrastructure must be built. All these factors have an impact on the local ecosystem and communities. One key question is, therefore, how populations living alongside future renewable hydrogen and derivative hubs, especially those situated in developing economies rich in renewable resources aiming to export, can benefit from potential socio-economic advantages in the sector.

BALANCING LOCAL AND INTERNATIONAL MARKET FOCUS TO ENCOURAGE SUSTAINABLE INDUSTRIAL DEVELOPMENT

The uptake of renewable hydrogen and derivative commodities' markets presents opportunities for developing economies across Africa, Latin America and the Middle East with abundant solar and wind resources. Such economies are uniquely positioned to produce cost-competitive renewable hydrogen production, offering them a strong comparative advantage in the international trade of green hydrogen and its derivatives. In this regard, collaborative efforts would contribute to pooling resources, exchanging expertise, and accelerating hydrogen infrastructure development (IRENA UNIDO and IDOS, 2024). Harnessing trade policies as part of comprehensive hydrogen strategies, such as facilitating trade in environmental goods, services, and renewable energy technologies as well as supporting the adoption of robust international standards can help create a conductive investment environment and scale up sustainable production.

There are industrial development opportunities both upstream and downstream in the value chain. How much the sector can contribute to industrial development depends on how much of the value is captured locally. This consideration will need to be balanced with the need to ensure high-quality low-cost technology and equipment produced in other economies.

One approach to increase upstream value creation is to develop facilities and capabilities for the manufacture of components and equipment for renewable generation, electrolysers, and ammonia and methanol production plants. Currently, manufacturing capacities of components and systems for renewable sectors such as solar PV and wind are concentrated in a relatively small number of economies (GWEC, 2024). This concentration has contributed to important cost reductions of solar and wind equipment thanks to economies of scale. There is therefore a trade-off between more geographically diversified production and a faster reduction in production cost – and, ultimately, price.

Electrolyser manufacturing capacity is concentrated in Europe and China, which account for two-thirds of global manufacturing capacity. However, to align with the Paris Agreement goal to limit global warming to 1.5°C, global electrolyser capacity needs to increase to 5,722 GW by 2050 (IRENA, 2023a). This would offer opportunities for a more geographically diversified manufacturing structure. Developing local manufacturing for some of the components, while importing the more technically specialised ones, could be another way to enhance value creation upstream.

One approach to maximise value downstream involves not only generating renewable hydrogen, but also expanding to produce derivatives and finished products, *e.g.*, steel. This would allow for the replacement of local usage of fossil fuel-derived ammonia, methanol and kerosene, with green alternatives. Given the difficulties associated with transporting hydrogen, producing and shipping derivatives may be preferable, particularly if the products will be used as feedstock or will be used directly in the import market without reconversion to hydrogen. Some countries, like Kenya, have already outlined an approach that considers the balance of opportunities for local industrial development and future exports (see Box 3).

Box 3

CASE STUDY **Kenya hydrogen roadmap and sustainable industrial development**

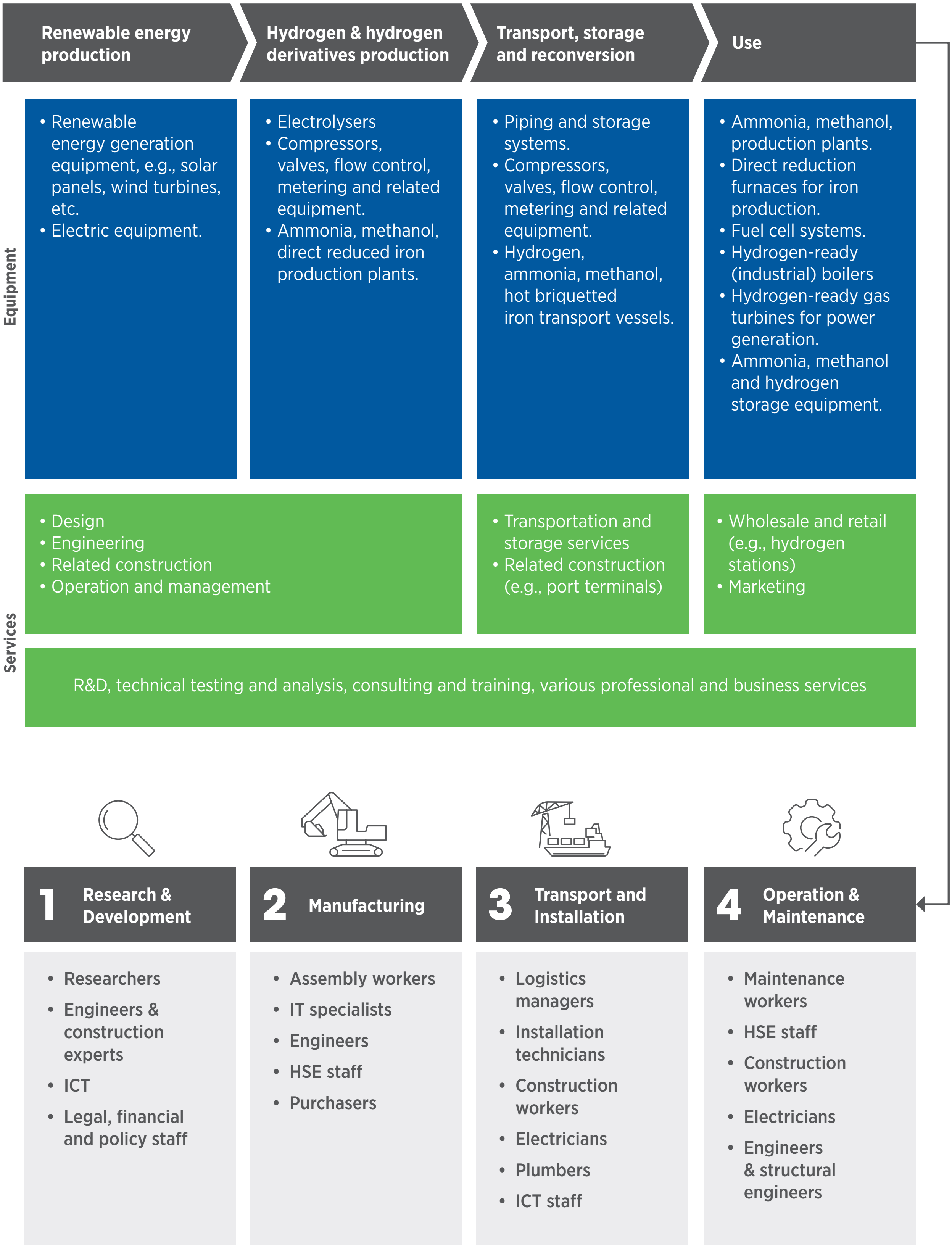
After releasing its Hydrogen Roadmap in October 2023, the Kenyan Energy and Petroleum Regulatory Authority issued guidelines on green hydrogen and its by-products in May 2024. The purpose is to provide a step-by-step guide on the sustainability criteria for green hydrogen and its derivatives in Kenya. Kenya currently relies on renewable energy sources for about 90% of its electricity grid, with a goal to achieve 100% renewable energy share by 2030. The agricultural sector is vital to Kenya's economy, and the country aims to gradually develop renewable ammonia production at a large scale, reducing the need for fossil fuel-based fertiliser imports. The gradual approach would enable producers in the country to integrate best practices in the further development of the sector and may turn Kenya from a net importer to a net exporter of sustainable fertilisers. For instance, the Kenyan government has established special export and public economic zones where these projects can be developed.

Sources: (Ministry of Energy and Petroleum, 2023).

EMBEDDING JOB CREATION IN NATIONAL ACTION PLANNING FOR HYDROGEN AND THE DERIVATIVE SECTORS

IRENA's analysis indicates that investments in the hydrogen sector could create 3.8 million jobs by 2030 and 6.5 million jobs by 2050 (IRENA, 2023a). However, it is important to consider where in the value chain these jobs will emerge and whether they will be long-term or only exist during the construction phase. For example, there may be a shift in the number of people needed and the types of jobs once the value chain is established. Construction workers will be required in large numbers during the construction phase, while maintenance and operation technicians will be in demand later during the operational phase (PtX Hub, 2024).

Figure 6 Overview of sample profession types required for the renewable hydrogen and derivative sector



Notes: ICT = information and communication technology ; IT = information technology; HSE = health, safety and environment.
Source: Adapted from (IRENA, 2024b; IRENA *et al.*, 2023).

Other factors that affect job creation potential are linked to industrial development. The extent to which a country captures value in the entire production process impacts the number and types of jobs created in both the short and long term.

Given that the renewable hydrogen and derivative sector is still in its early stages, there are different methods for assessing the job creation potential. Some governments are addressing job creation and skills development in their hydrogen strategies, but their approaches vary. Developing the full supply chain may lead to synergies between local industrial development and enhanced employment prospects for a qualified local workforce. Therefore, local workforce training is crucial to maximising employment effects. After assessing the local job creation potential, the next step is to assess the required skills and training to develop the workforce and enhance local employment effects.

COMMUNITY AND STAKEHOLDER ENGAGEMENT GUIDELINES FOR PROJECT DEVELOPERS

Large-scale renewable hydrogen and derivatives projects require significant land and water resources as well as infrastructure. To ensure long-term success, social acceptance is vital, and must be encouraged via collaboration with local communities, labour groups, environmental justice organisations and indigenous communities. These projects would not only help to achieve the goals of the Paris Agreement, but would also have a positive impact on local communities and minimise environmental risks.

Community engagement must remain a priority, involving local decision-making, sharing of benefits, training to develop local capacity, and the implementation of environmental and social safeguards. Integrating these projects with broader economic development plans is crucial, as neglecting these efforts may risk damaging the industry's reputation, leading to rejection by local stakeholders and communities. Securing and maintaining a project's social license to operate[6] is advantageous, and ongoing approval within the local community and among other stakeholders can be an important success factor for infrastructure development (IRENA, forthcoming). Thus, initiating and sustaining community and stakeholder engagement throughout all project stages is essential. There is no "one size fits all" solution, as appropriate community engagement depends, of course, very much on the local context, conditions, and types of stakeholders to be involved.

Some economies directly address community and stakeholder engagement within their hydrogen strategies or other policy and regulatory frameworks, and provide guidance on how these activities should be planned for and managed. The United States, for instance, has included community engagement as part of its Regional Clean Hydrogen Hubs (H_2Hubs) program. In October 2023, the Office of Clean Energy Demonstrations announced the selection of seven H_2Hubs for award negotiation. All applicants were required to complete a community benefit plan for the H_2Hubs and are expected to implement the appropriate scope of community benefits activities for each phase. They will also be required to measure and report metrics during each phase and update their plan based on future activities and lessons learned (DoE, 2023).

[6] *Social license is generally described as an ongoing acceptance of and approval toward a project or company granted by local communities and stakeholders, gained through trust and transparency, active engagement by a community in making decisions about the project, and making sure that benefits from the project are equitably distributed. It secures long-term support and cooperation through respect for local values and sustainable practices (Raufflet et al., 2013).*

Figure 7 Community engagement guidelines for hydrogen hubs.

APPLICATION	**Develop approach to community engagement and begin outreach to community, energy justice, and labour representatives**	• Conduct social characterisation and stakeholder mapping • Carry out initial outreach to impacted communities and labor groups to identify needs and opportunities • Conduct self-assessment of company's ability to perform inclusive two-way engagement
PHASE 1: DETAILED PLAN	**Engage surrounding communities for consultation, with the end aim of mutually beneficial project plan**	• Discuss community needs through two-way engagement • Conduct assessments of benefits and negative impacts and where they flow • Set a transparent process for tracking and incorporating feedback
PHASE 2: DEVELOP, PERMIT, FINANCE	**Formalise project/ community collaboration through legally binding community and workforce agreements**	• Develop agreements through negotiations between developers, community groups, and labour unions • Establish and agree on metrics to measure compliance
PHASE 3: INSTALL, INTEGRATE, CONSTRUCT	**Meet community benefits formally agreed to for construction phase and provide pathway to track progress**	• Implement construction-phase community benefits strategy • Hold listening sessions with company representatives for transparency, project development updates, and sharing of community opportunities
PHASE 4: RAMP UP AND OPERATE	**Track and report progress of engagement and community benefits through operations**	• Provide continuous project information updates for community benefit transparency • Provide ongoing communication and feedback • Produce final report on accomplishments, findings, and plans for steady state operations

Source: Adapted from (Bukirwa *et al.*, 2024).

Panama has also placed social acceptance and community involvement at the centre of its hydrogen strategy. It prioritises engagement with communities that are likely to be neighbours to renewable hydrogen facilities. This essential acknowledgement of the importance of dialogue and community involvement might also be extended to international collaboration. Here, the involvement of regional organisations and agencies dedicated to renewable hydrogen is crucial. Fostering communication among communities, including those with experience with renewable hydrogen projects, is also a key factor. Sharing information, knowledge and experiences will facilitate the achievement of decarbonisation goals in the clean energy sector (IRENA, 2024d).

CONCLUSIONS

Hydrogen and hydrogen-derived commodities (ammonia, methanol and e-kerosene) are expected to play a crucial role in the energy transition and – in particular – the decarbonisation of many hard-to-abate end uses across industry and heavy-duty transport. Varying distributions of renewable energy resources mean that it may be cheaper to produce these commodities in some geographies relative to others, and many economies and regions see an opportunity to develop international markets and trade in these products. This report focusses on enabling measures and policy priorities across physical, institutional and social dimensions which could be used to foster international markets for these commodities. These enabling measures are discussed in detail in the body of this briefing, and a summary of considerations is are set out below.

SUMMARY OF ENABLERS

1 **Holistically consider resource availabilities and requirements when planning infrastructure development** and ensure adequate supply of renewable electricity, water and carbon.

2 **Prioritise distribution infrastructure as a means to ensure market access for producers** and consider how consumers will access the traded commodities.

3 **Support the development of diversified supply chains across these sectors** to enhance resilience.

4 **Align standards and reduce divergences in certification** to ensure credible global markets and foster consumer confidence across international borders.

5 **Calibrate government support and procurement** to facilitate demand, de-risk off-take and drive supply chain development.

6 **Rebalance tariffs** for key products and services along the renewable hydrogen and derivatives value chains to reduce costs and encourage technology uptake.

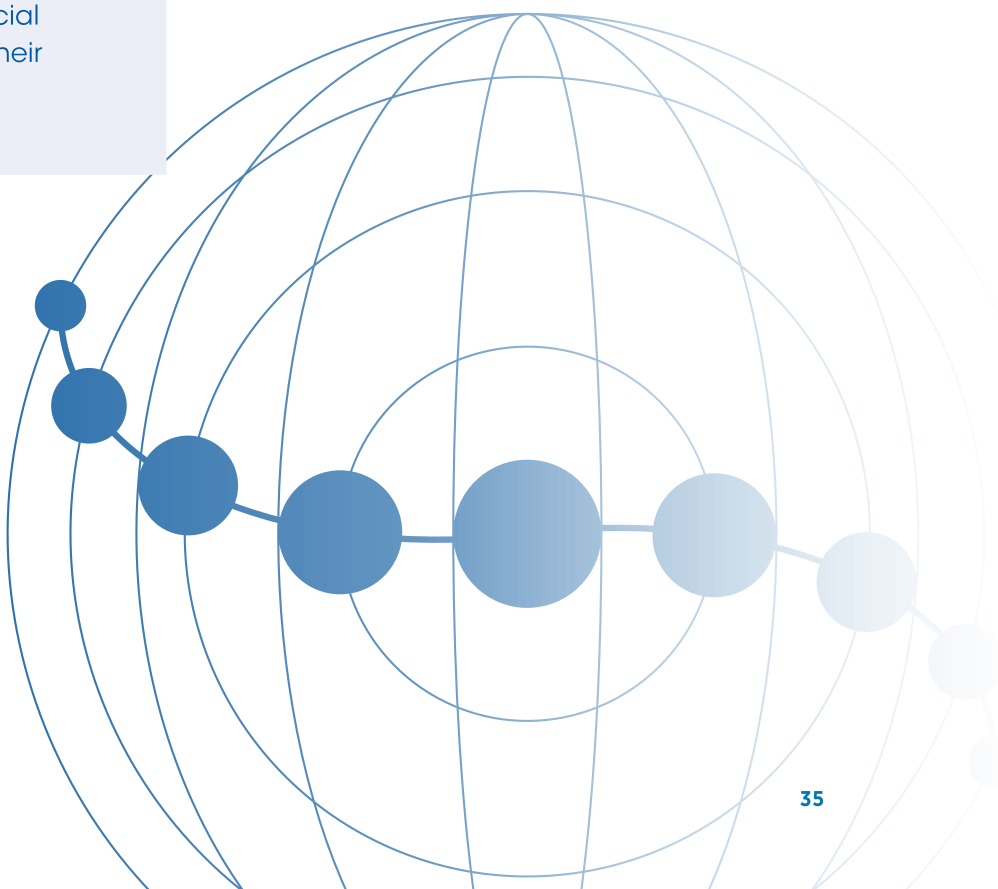
7 **Coordinate carbon pricing mechanisms** to enhance competitiveness and level the playing field.

8 **Harness international cooperation**, and use the fora available to identify best practices, increase efficiency, and ensure equitable growth.

9 **Balance local and international market focus** to encourage sustainable industrial development and consider which markets will add the most value locally.

10 **Embed job creation in national action planning** for hydrogen and the derivative sectors and understand the opportunities available to use industrial development to achieve socioeconomic progress.

11 **Develop community and stakeholder engagement guidelines** to follow and encourage project developers to build genuine social acceptance for their projects.



REFERENCES

AFID (n.d.), "Alliance for Industry Decarbonization", https://allianceforindustrydecarbonization.org/ (accessed 10 July 2024).

Africa Green Hydrogen Alliance (2024), "Sustainable fiscal regimes for green hydrogen projects: Financial modelling recommendations and tools", https://gh2.org/sites/default/files/2024-05/AGHA_Fiscal Policies Recommendations_May 2024.pdf (accessed 20 September 2024).

Bukirwa, P., *et al.* (2024), "Delivering Equitable and Meaningful Community Benefits via Clean Hydrogen Hubs", *RMI*, https://rmi.org/delivering-equitable-and-meaningful-community-benefits-via-clean-hydrogen-hubs/ (accessed 25 October 2024).

COP28 (2023), "COP28 Declaration of Intent on Mutual Recognition of Certification Schemes for Renewable and Low-Carbon Hydrogen and Hydrogen Derivatives", www.cop28.com/en/cop28-uae-declaration-on-hydrogen-and-derivatives

Deloitte (2023), "Green hydrogen: Energizing the path to net zero", Deloitte.

DoE (2023), "Regional Clean Hydrogen Hubs", *US Department of Energy*, https://www.energy.gov/oced/regional-clean-hydrogen-hubs-0 (accessed 21 December 2023).

EEA (2019), "Ammonia emissions from agriculture continue to pose problems for Europe", *European Environment Agency*, https://www.eea.europa.eu/highlights/ammonia-emissions-from-agriculture-continue (accessed 20 September 2024).

ENTSOG, *et al.* (n.d.), "How to transport and store hydrogen – facts and figures", *The European Network of Transmission System Operators for Gas*, https://www.entsog.eu/sites/default/files/2021-05/ENTSOG_GIE_HydrogenEurope_QandA_hydrogen_transport_and_storage_FINAL_0.pdf (accessed 24 October 2024).

European Union (2023), "Carbon Border Adjustment Mechanism (CBAM): Hydrogen sector", *Customs & Tax EU Learning Portal*, https://customs-taxation.learning.europa.eu/course/view.php?id=804&section=1 (accessed 20 September 2024).

Gale, F., *et al.* (2024), "Renewable hydrogen standards, certifications, and labels: A state-of-the-art review from a sustainability systems governance perspective", *International Journal of Hydrogen Energy*, vol. 59, pp. 654–67, https://doi.org/10.1016/j.ijhydene.2024.02.038

Global Commission on the Economics of Water (2024), "The Economics of Water: Valuing the Hydrological Cycle as a Global Common Good", OECD Environment Directorate, Paris, https://economicsofwater.watercommission.org/report/executive-summary-economics-of-water.pdf (accessed 30 October 2024).

Government of Chile (2024), "Green Hydrogen Action Plan 2023-2030", Government of Chile, Santiago, https://energia.gob.cl/sites/default/files/documentos/green-hydrogen_action-plan.pdf

GWEC (2024), "Wind Turbine Manufacturers See Record Year Driven by Growth in Home Markets", *Global Wind Energy Council*, https://gwec.net/wind-turbine-manufacturers-see-record-year-driven-by-growth-in-home-markets/ (accessed 13 September 2024).

Hunton Andrews Kurth (2024), "Chilean Government Releases its Green Hydrogen Action Plan 2023-2030", *Legal Updates*, https://www.huntonak.com/insights/legal/chilean-government-releases-its-green-hydrogen-action-plan-2023-2030 (accessed 20 September 2024).

Hydrogen Council, and McKinsey & Company (2024), "Emerging trade corridors for hydrogen and its derivatives", https://hydrogencouncil.com/wp-content/uploads/2024/05/Emerging-trade-corridors-for-hydrogen-and-its-derivatives.pdf (accessed 23 October 2024).

IEA, *et al.* (2023), *The Breakthrough Agenda Report 2023*, International Energy Agency, International Renewable Energy Agency, United Nations Climate Change High-Level Champions, Geneva and Abu Dhabi, www.irena.org/Publications/2023/Sep/Breakthrough-Agenda-Report

IRENA (2020), *Green hydrogen: A guide to policy making*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2020/Nov/Green-hydrogen

IRENA (2021), *Reaching zero with renewables: Biojet fuels*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2021/Jul/Reaching-Zero-with-Renewables-Biojet-Fuels (accessed 17 November 2021).

IRENA (2023a), *World energy transitions outlook 2023: 1.5°C pathway*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2023/Jun/World-Energy-Transitions-Outlook-2023

IRENA (2023b), *Creating a global hydrogen market: Certification to enable trade*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2023/Jan/Creating-a-global-hydrogen-market-Certification-to-enable-trade

IRENA (2024a), *Green hydrogen strategy: A guide to design*, International Renewable Energy Agency, Abu Dhabi, https://www.irena.org/Publications/2024/Jul/Green-hydrogen-strategy-A-guide-to-design

IRENA (2024b), *Shaping sustainable international hydrogen value chains*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2024/Sep/Shaping-sustainable-international-hydrogen-value-chains

IRENA (2024c), *Global trade in green hydrogen derivatives: Trends in regulation, standardisation and certification*, International Renewable Energy Agency, Abu Dhabi, https://www.irena.org/Publications/2024/Oct/Global-trade-in-green-hydrogen-derivatives-Trends-in-regulation-standardisation-and-certification

IRENA (2024d), *International co-operation to accelerate green hydrogen development*, International Renewable Energy Agency, Abu Dhabi, https://www.irena.org/Publications/2024/Apr/International-co-operation-to-accelerate-green-hydrogen-deployment

IRENA (forthcoming), *Just Energy Transitions for communities: Large-scale wind and solar projects in Sub-Saharan Africa*, International Renewable Energy Agency, www.irena.org/Publications

IRENA and AEA (2022), *Innovation Outlook: Renewable Ammonia*, International Renewable Energy Agency, Abu Dhabi, https://www.irena.org/publications/2022/May/Innovation-Outlook-Renewable-Ammonia

IRENA and Bluerisk (2023), *Water for hydrogen production*, International Renewable Energy Agency and Bluerisk, Abu Dhabi, www.irena.org/Publications/2023/Dec/Water-for-hydrogen-production

IRENA and Methanol Institute (2021), *Innovation outlook: Renewable methanol*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2021/Jan/Innovation-Outlook-Renewable-Methanol

IRENA, UNIDO and IDOS (2024), *Green Hydrogen for Sustainable Industrial Development*, https://www.irena.org/Publications/2024/Feb/Green-hydrogen-for-sustainable-industrial-development-A-policy-toolkit-for-developing-countries

IRENA and WTO (2023), *International trade and green hydrogen: Supporting the global transition to a low-carbon economy*, www.irena.org/Publications/2023/Dec/International-trade-and-green-hydrogen-Supporting-the-global-transition-to-a-low-carbon-economy

ISA (n.d.), "Chile", *International Solar Alliance, Green hydrogen Innovation Centre*, https://isa-ghic.org/countries/chile (accessed 20 September 2024).

ISO (2023), "SO/TS 19870:2023 Hydrogen technologies Methodology for determining the greenhouse gas emissions associated with the production, conditioning and transport of hydrogen to consumption gate", https://www.iso.org/standard/65628.html (accessed 20 December 2023).

Keating, D. (2024), "Sustainable marine fuels: the key to finally decarbonise shipping?", *Euractiv*, https://www.euractiv.com/section/energy-environment/news/sustainable-marine-fuels-the-key-to-finally-decarbonise-shipping/ (accessed 20 September 2024).

Köppl, A., and Schratzenstaller-Altzinger, M. (2021), "Effects of Environmental and Carbon Taxation. A Literature Review", In WIFO Working Papers 619, WIFO.

Linsenmeier, M., *et al.* (2022), *Policy Sequencing Towards Carbon Pricing – Empirical Evidence From G20 Economies and Other Major Emitters*, International Monetary Fund, https://www.imf.org/en/Publications/WP/Issues/2022/04/01/Policy-Sequencing-Towards-Carbon-Pricing-Empirical-Evidence-From-G20-Economies-and-Other-515609

Malpass, D. (2022), "A transformed fertilizer market is needed in response to the food crisis in Africa", *World Bank Blogs*, https://blogs.worldbank.org/en/voices/transformed-fertilizer-market-needed-response-food-crisis-africa (accessed 20 September 2024).

Methanol Institute (2020), "Methanol Institute Position on Council Directive 2003/96/EC Restructuring the Community Framework for the Taxation of Energy Products and Electricity", https://www.methanol.org/wp-content/uploads/2020/04/Energy-Taxation-Directive-final.pdf (accessed 20 September 2024).

Ministry of Energy and Petroleum (2023), "Green Hydrogen Strategy and Roadmap for Kenya", https://www.eeas.europa.eu/sites/default/files/documents/2023/GREEN%20HYDROGEN%20EXEC_0209_0.pdf (accessed 6 November 2023).

PtX Hub (2024), "Skills and Jobs in the Context of Power-to-X", https://ptx-hub.org/wp-content/uploads/2024/02/International-PtX-Hub_202402_Sustainability-Briefing-5_skills-and-jobs.pdf (accessed 23 September 2024).

Renewables Now (REN21) (n.d.), "Renewables 2024: Global Status Report", https://www.ren21.net/gsr-2024/modules/global_overview/02_policy/#top (accessed 20 September 2024).

Steenblik, R. (2020), "How Can a Six-Digit Trade Code Help the Environment?", *International Institute for Sustainable Development*, https://www.iisd.org/articles/trade-code-environment (accessed 20 September 2024).

Uddin, M. N., and Wang, F. (2024), "Fuelling a Clean Future: A Systematic Review of Techno-Economic and Life Cycle Assessments in E-Fuel Development", *Applied Sciences*, vol. 14/16, pp. 7321, https://doi.org/10.3390/app14167321

UNIDO (2023a), *Green Hydrogen Industrial Clusters*, United Nations Industrial Development Organization, https://www.unido.org/sites/default/files/files/2023-08/GH2_ClusterGuidelines_0.pdf (accessed 23 September 2024).

UNIDO (2023b), "Supporting an inclusive global trade of low carbon hydrogen", *United Nations Industrial Development Organization*, https://hydrogen.unido.org/news/supporting-inclusive-global-trade-low-carbon-hydrogen (accessed 23 October 2024).

Wang, B., *et al.* (2024), "Sustainable aviation fuels: Key opportunities and challenges in lowering carbon emissions for aviation industry", *Carbon Capture Science & Technology*, vol. 13, pp. 100263, https://doi.org/10.1016/j.ccst.2024.100263

WCO (2023), "How can the HS identify the green status of equipment? was the fundamental question of the fifth Symposium on Visualising a greener HS to support environmentally sustainable trade", World Customs Organization, https://www.wcoomd.org/zh-cn/media/newsroom/2023/february/how-can-the-hs-identify-the-green-status-of-equipment-was-the-fundamental-question.aspx

World Bank (2024), *State and Trends of Carbon Pricing 2024*, World Bank Group, Washington, D.C., https://openknowledge.worldbank.org/entities/publication/b0d66765-299c-4fb8-921f-61f6bb979087

World Bank Group (n.d.), "State and Trends of Carbon Pricing Dashboard", Washington D.C., https://carbonpricingdashboard.worldbank.org/ (accessed 20 September 2024).

WTO (2022), *World trade report 2022: climate change and international trade*, World Trade Organization, Geneva, Switzerland, https://www.wto.org/english/res_e/booksp_e/wtr22_e/wtr22_e.pdf

WTO (2023a), *Trade policy tools for climate action*, World Trade Organization, Geneva, Switzerland, https://www.wto.org/english/res_e/publications_e/tptforclimataction_e.htm

WTO (2023b), *Re-globalization for a secure, inclusive and sustainable future*, World Trade Organization, Geneva, https://www.wto.org/english/res_e/booksp_e/wtr23_e/wtr23_e.pdf

WTO (2024a), "World Trade Organization Analytical Databases", World Trade Organization, Geneva.

WTO (2024b), "Statement by the TESSD co-convenors", *WT/MIN(24)/11/Add.3*, In Trade and environmental structured discussions (TESSD), World Trade Organization, Abu Dhabi, https://docs.wto.org/dol2fe/Pages/SS/directdoc.aspx?filename=q:/WT/MIN24/11A3.pdf&Open=True (accessed 20 September 2024).

WTO (n.d.), "Trade and environmental sustainability", *World Trade Organization*, https://www.wto.org/english/tratop_e/tessd_e/tessd_e.htm

IRENA
International Renewable Energy Agency

www.irena.org

World Trade Organization

www.wto.org