UNIVERSITY OF CAMBRIDGE | Cambridge Industrial Innovation Policy | GSCO Global Supply Chain Observatory | IfM Industrial Resilience Research Group

A framework for responsible supply chains in critical minerals: the case of green hydrogen

POLICY BRIEF

About this policy brief

This policy brief explores the critical minerals and green hydrogen nexus, highlighting the opportunities and risks that arise as the demand for clean energy technologies accelerates. It examines how developing and least developed countries can leverage the green transition for inclusive industrialisation. The brief proposes a framework for responsible supply chains in critical minerals organised around five key principles and illustrated with practical actions and case studies.

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Images stock.adobe.com and Microsoft stock

Acknowledgements

The authors would like to thank the following individuals for their contributions to this policy brief: Dr Smeeta Fokeer, Industrial Policy and Development Officer, United Nations Industrial Development Organization (UNIDO); Dr Mukesh Kumar, Associate Professor and Head of the Industrial Resilience Research Group, Institute for Manufacturing, University of Cambridge; Professor Chux Daniels, University of Pretoria and Senior Research Fellow, University of Sussex; Dr David Leal-Ayala, Cambridge Industrial Innovation Policy, IfM Engage, Institute for Manufacturing, University of Cambridge; and Jessica Ocampos, Fellow of Cambridge Centre for Environment, Energy and Natural Resource Governance, University of Cambridge and Director of Camnexus.

Cambridge, United Kingdom | 2025

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Executive summary

The global market for energy transition minerals, valued at over USD300 billion, is projected to grow sharply over the next decade, with demand expected to outpace supply..[1] These critical minerals are indispensable for clean energy technologies, yet their supply chains are exposed to considerable risks arising from geographic concentration, political uncertainty, and environmental pressures..[2]

Green hydrogen (GH2), increasingly recognised as a cornerstone of decarbonisation in hard-to-abate sectors such as steel, chemicals, shipping, and aviation, relies on secure and sustainable supplies of critical minerals. But the mining sector that underpins these value chains faces significant challenges, including greenhouse gas emissions, ecological degradation, and social and human rights concerns. Expanding extraction to meet rising demand risks exacerbating these challenges, particularly in water-scarce regions, fragile ecosystems, Indigenous territories, and conflict-affected areas..[3]

This policy brief explores the nexus between green hydrogen and critical minerals, proposing a framework for responsible supply chains that align the expansion of GH2 with sustainable development. The framework is structured around five guiding principles:

1. Ensure decent work. Safeguarding workers across formal and informal supply chains from exploitation and unsafe conditions.

2. Reduce environmental and social impacts. Minimising ecological harm and protecting community rights to land, water, and wellbeing.

3. Facilitate inclusive community partnerships. Ensuring meaningful participation and fair benefit-sharing for local and Indigenous communities.

4. Strengthen governance, transparency, and accountability. Requiring robust disclosure, independent oversight, and anti-corruption safeguards across supply chains.

5. Promote inclusive and sustainable industrialisation. Enabling producer countries to capture lasting value through technology transfer, local capacity-building, and equitable global partnerships.

The transformative potential of green hydrogen in the energy transition depends on advancing its technology and building resilient, ethical supply chains for critical minerals. By adopting the principles outlined in this framework, stakeholders can ensure that the benefits of green hydrogen—and other clean energy technologies—extend beyond decarbonisation to foster inclusive and sustainable prosperity.

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[1] International Energy Agency (2024). *Global critical minerals outlook 2024*. IEA.
[2] Coulomb, R., Dietz, S., Godunova, M. and Nielsen, T. B. (2015). *Critical minerals today and in 2030: An analysis for OECD countries*. OECD Environment Working Papers, No. 91. OECD Publishing
[3] Heffron, R. J. (2020). The role of justice in developing critical minerals. *The extractive Industries and Society*, 7(3): 855–863.

1. Introduction

Valued at more than USD300 billion, the global market for energy transition minerals is set to grow significantly, with forecasts indicating that demand will exceed supply over the coming decade..[4] These resources, essential for clean energy technologies, are often referred to as critical minerals: they are economically significant and difficult to substitute, with supply chains that are exposed to disruption because of geographic concentration, political uncertainty, and environmental pressures..[5]

Critical minerals are vital for the growth of green hydrogen (GH2), which is becoming a key component of decarbonisation strategies in hard-to-abate sectors such as steel, chemicals, shipping, and aviation. Yet the mining sector that underpins these supply chains faces increasing scrutiny. Mining accounts for 2–3% of global carbon emissions and is under mounting pressure to transition to renewable energy, embed circular economy practices, and reduce ecological footprints..[6]

At the same time, the rapid expansion of mining to meet the demand for clean technology risks deepening environmental degradation and human rights violations, especially in contexts of water scarcity, fragile ecosystems, Indigenous territories, and conflict-affected regions..[7] These challenges underline the importance of governance systems that safeguard human rights, promote environmental stewardship, and ensure that producer countries capture fair and lasting benefits from their resources.

Against this backdrop, this policy brief examines the nexus between critical minerals and green hydrogen. It proposes a framework for responsible supply chains that can help to align the expansion of green hydrogen with sustainable development, ensuring that the benefits of this emerging sector are widely and equitably shared. It is structured as follows:

- Section 2 provides an overview of green hydrogen production, technologies, and critical mineral requirements.
- Section 3 explores the pivotal role of developing countries in supplying these minerals.
- Section 4 introduces a framework for responsible supply chains in critical minerals organised around five key principles and illustrated with practical actions and case studies.
- Section 5 concludes with reflections on policy implications.
- Appendix A provides a summary table of the frameworks and initiatives reviewed.

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[4] International Energy Agency (2024). *Global critical minerals outlook 2024*. IEA.
[5] Coulomb, R., Dietz, S., Godunova, M. and Nielsen, T. B. (2015). *Critical minerals today and in 2030: An analysis for OECD countries*. OECD Environment Working Papers, No. 91. OECD Publishing
[6] Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development, IGF (2023). *The impact of climate change on the mining sector*.
[7] Heffron, R. J. (2020). The role of justice in developing critical minerals. *The extractive Industries and Society*, 7(3): 855–863.

2. Critical minerals and green hydrogen

Hydrogen production is commonly described using "colour" labels (grey, blue, green), depending on the associated carbon emissions.[8] Among these, green hydrogen (GH2) is produced by using renewable electricity to split water into hydrogen and oxygen, with water as its only byproduct.

Because colour labels vary across studies[9] and often overlook new and emerging production methods, the International Energy Agency (IEA) recommends defining GH2 by its emissions intensity, allowing each country to adapt its approach to align with its unique decarbonisation goals.[10] In this context, GH2 refers to hydrogen generated with zero or minimal carbon emissions,[11] tailored to fit within each nation's sustainability strategy.

Although there are many ways to produce GH2, the most sought-after methods use electrolyser technology, mainly alkaline (ALK) and polymer electrolyte membrane/proton exchange membrane (PEM) electrolysers. Each has a respective market share of around 60% and 30% within GH2 production equipment.[12]

Despite the increasing interest in GH2, the adoption rate remains low, currently accounting for less than 1% of global hydrogen production.[13] This is because, while it has attracted attention because of its role in contributing to relevant climate change targets, its adoption faces several barriers, including technologies in early stages of development, the need for significant investment to develop capacity and infrastructure, and other enabler factors required for GH2 scale-up.[14]

Critical mineral supply is another factor limiting the scale-up of electrolysers.[15] These minerals are essential to the economic or national security of a nation state.[16] The list of critical minerals[17] in the IRENA *Geopolitics of the Energy Transition* report is used as a reference for this policy brief.

Electrolysers, the technology driving GH2 production, rely on elements derived from critical minerals. Six key elements are vital for producing the ALK and PEM electrolysers needed to expand GH2 output: aluminium, iridium, nickel, platinum, titanium, and zirconium. Securing a stable supply of these minerals is crucial to scaling GH2 production and supporting a sustainable energy transition.

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[8] Ajanovic, A., Sayer, M. and Haas, R. (2022). The economics and the environmental benignity of different colors of hydrogen. *International Journal of Hydrogen Energy*, 47: 57. https://doi.org/10.1016/j.ijhydene.2022.02.094
[9] Ibid.
[10] Bennett, S., Evangelopoulou, S., Fajardy, M., Greenfield, C., Pavan, F. and Pizarro Alonso, A. (2023). *Towards hydrogen definitions based on their emissions intensity*. Paris: IEA.
[11] Hulst, N. v. (2019). *The clean hydrogen future has already begun.*
[12] Ansari, D., Grinschgl, J. and Pepe, J. M. (2022). *Electrolysers for the Hydrogen Revolution*. SWP.
[13] IEA (2024). *Global Hydrogen Review 2024*. IEA, Paris.
[14] Fokeer, S., Sievernich, J., Heredia, A., Bianco, E., Melnikov, Y., Strohmaier, R., Nunez, A. and Stamm, A. (2023). *Green Hydrogen for Sustainable Industrial Development A Policy Toolkit for Developing Countries*. UNIDO.
[15] Greenwald, J. E., Zhao, M. and Wicks, D. A. (2024). *Critical mineral demands may limit scaling of green hydrogen production*. Frontiers in Geochemistry.
[16] US Geological Survey (n.d.) *What is a critical mineral?*
[17] IRENA. (2024). *Geopolitics of the energy transition: Energy security, International Renewable Energy Agency*. Abu Dhabi.

3. The role of developing countries in the supply of critical minerals

Developing countries and emerging economies are key players in the supply chain of critical minerals for green hydrogen (GH2) production, supplying essential materials for electrolyser components. Using data from the US Geological Survey (USGS) and the United Nations Conference on Trade and Development (UNCTAD) classification of economies,[18] we see that a significant portion of critical mineral supply originates from these regions. Specifically, 68% of countries involved in GH2-relevant mineral production are classified as developing economies or least developed countries (LDCs), with LDCs alone accounting for 16%. This does not include regions grouped as "other countries" or capture contributions from politically sensitive areas with limited data availability.

Aluminium, a crucial input for electrolysers and the second most traded mineral globally, illustrates the significance of developing economies in the green hydrogen supply chain.[19] While only half of the producing countries fall into this category, in 2023 they accounted for 74% (with China accounting for 59%) of global aluminium ore production.

Platinum and iridium, essential for the electrodes of proton exchange membrane (PEM) electrolysers, are predominantly co-sourced from platinum ore.[20] Developing countries contributed 79% of global supply in 2023.

Nickel, vital for electrodes in alkaline (ALK) electrolysers, presents a similar pattern. In 2023 developing countries sourced 74% of global production.

Titanium, used as the porous transport layer in PEM electrolysers, is largely derived from ilmenite and rutile ores.[21],[22] In 2023 developing and least developed economies accounted for 80% of global ilmenite production, with 26% coming from the least developed category alone. For rutile, two-thirds of producing countries fell within these classifications, together contributing 53% of production.

Similar to titanium, zirconium is found in two major minerals: zircon and baddeleyite. In 2023, 80% of zirconium-producing countries were developing or least developed economies, contributing to 54% of the total supply, with 13% sourced from LDCs.

Taken together, these figures highlight the pivotal contribution of developing and least developed economies to the green hydrogen value chain. They also underscore the importance of establishing fair and transparent trade frameworks that advance global energy transition goals and ensure that the economic benefits of this emerging sector are equitably shared with the countries and communities that provide these essential resources.

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[18] UNCTAD Data Hub (n.d.). Classification of economies.

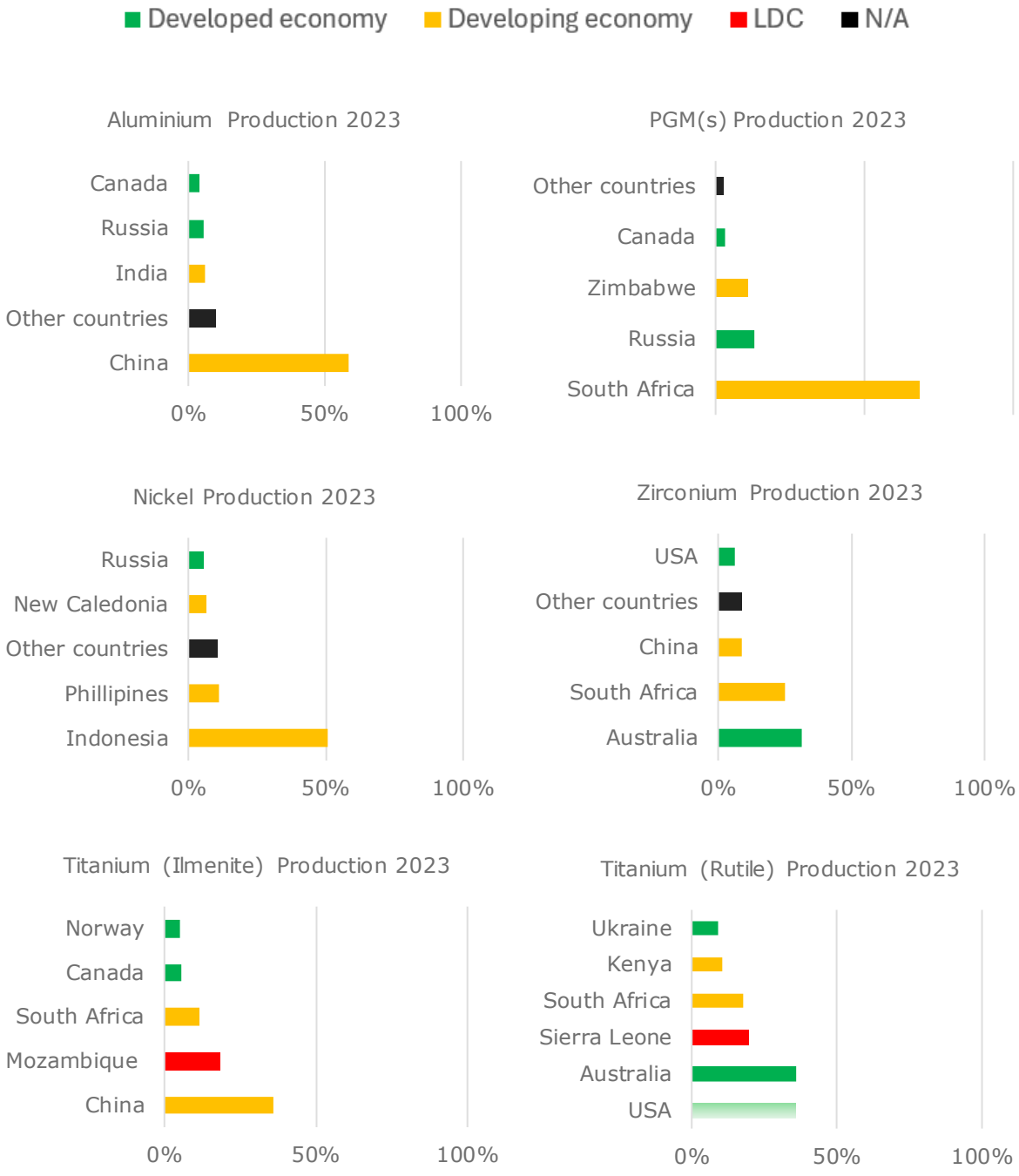
[19] Snoussi-Mimouni, M. and Avérous, S. (2024). *High demand for energy-related critical minerals creates supply chain pressures*.

[20] Chen, J. (2023). *Iridium: What it Is, Applications, Example*.

[21] Royal Society of Chemistry (n.d.). *Titanium*.

[22] Note that in this particular grouping of metals, the USA has double-counted materials, as the production value used for ilmenite includes rutile.

FIGURE 1: TOP PRODUCING COUNTRIES OF CRITICAL MINERALS RELEVANT FOR GREEN HYDROGEN



Note: LDC. This chart follows the UNCTAD classification of economies. But it is acknowledged that China may not be regarded as a developing economy under some criteria.

Source: USGS (2024). *Mineral Commodity Summaries 2024.* Available at: https://pubs.usgs.gov/publication/mcs2024

4. A framework for responsible supply chains in critical minerals

This section outlines a framework for responsible supply chains in critical minerals, structured around five guiding principles and associated actions for implementation. It also includes case studies that demonstrate how these actions can be applied in practice. The framework draws on a review of 22 leading strategies, initiatives, standards and studies that promote responsible supply chains in the critical minerals sector and related industries, with a focus on green hydrogen (GH2) production. A summary table of the documents reviewed is provided in Appendix A.

The five principles are:

1. Ensure decent work
2. Reduce negative environmental and social impacts
3. Facilitate inclusive community partnerships
4. Encourage transparency and accountability
5. Promote inclusive and sustainable industrialisation

Principle 1. Ensure decent work

Workers across the mining and hydrogen value chains, whether in formal, informal, or artisanal contexts, must be safeguarded against exploitation, unsafe conditions, and discrimination.

Key actions:

- Eliminate child and forced labour through strengthened due diligence, capacity-building for local regulators, and targeted interventions in artisanal and small-scale mining.[23]
- Uphold the International Labour Organization's core labour standards: freedom of association, collective bargaining, equal pay, and non-discrimination.[24]
- Support enforcement in weak jurisdictions through multi-stakeholder partnerships (industry, government, civil society) and international oversight mechanisms, building on lessons from collaborative initiatives like the Global Battery Alliance (see Box 1).
- Ensure safe, healthy workplaces with training, protective equipment, and grievance mechanisms.[25]
- Promote gender equality and social inclusion through inclusive recruitment, targeted skills development, and the creation of career pathways for under-represented groups.[26]

[23] See for example Global Sustainability Standards Board (2024). *GRI 14: Mining Sector 2024*; ILO Declaration on Fundamental Principles and Rights at Work, 1998 (revised 2022).
[24] ILO Declaration on Fundamental Principles and Rights at Work, 1998 (revised 2022).
[25] See for example Initiative for Responsible Mining Assurance (IRMA). *Standards*.
[26] See for example Global Sustainability Standards Board (2024). *GRI 14: Mining Sector 2024*.

- Leverage digital solutions to collect, verify, and disclose labour rights data, enabling benchmarking and continuous improvement across global supply chains..[27]

BOX 1. THE GLOBAL BATTERY ALLIANCE'S BATTERY PASSPORT AND DECENT WORK IN SUPPLY CHAINS

The "Battery Passport" of the Global Battery Alliance (GBA) is a global framework for sustainability reporting and certification, integrating labour rights' due diligence into transparent battery supply chains.

Founded in 2017 at the World Economic Forum, the GBA brings together more than 120 public and private stakeholders, including governments, industry leaders, civil society, and international organisations. Its goal is to establish a sustainable battery value chain by 2030, with decent work and labour rights' due diligence as a central pillar.

The Battery Passport is a pioneering digital certification and reporting scheme. It uses Digital Product Passport protocols to gather, verify, and share facility-level sustainability data across the supply chain. This system allows physical batteries to be graded for their sustainability performance, including compliance with labour standards.

Key features relevant to decent work include:

- Human Rights Index and Child Labour Index, which require companies to answer detailed questions about labour practices, risks, and mitigation measures.
- Rulebooks covering issues such as forced labour, child labour, Indigenous Peoples' rights, and biodiversity.
- Digital traceability systems to ensure transparency on the provenance and flow of critical materials like lithium, cobalt, copper, and graphite.

In 2023–24, the GBA piloted the Battery Passport with 10 industry consortia led by major global battery manufacturers, representing over 80% of the global electric vehicle battery market.

By integrating labour rights into supply chain transparency and certification, the Battery Passport demonstrates how digital tools and multi-stakeholder collaboration can strengthen the protection of workers in both mining and downstream processing. It offers a model for how decent work standards can be operationalised in practice, directly supporting fairer and more sustainable energy transitions.

Source: Global Battery Alliance (2025). Battery passport.

[27] See for example OECD (2016). *OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas*: Third Edition. Paris: OECD Publishing; UNIDO (2025). UNIDO's FairShare Programme.

Principle 2. Reduce negative environmental and social impacts

Extractive activities should minimise environmental damage and respect communities' rights to land, water, and wellbeing.

Key actions:

- Require comprehensive environmental and social impact assessments for authorisation of projects, including water withdrawal, biodiversity loss, carbon intensity, and impacts on traditional livelihoods.[28]
- Manage water use carefully, ensuring that project activities do not reduce communities' access to safe and sufficient water.[29] See the case of Chile's mining sector in Box 2.
- Assess gendered environmental and social impacts.[30]
- Apply the precautionary principle with clear criteria: prohibit projects in biodiversity hotspots, Indigenous territories (without truly free, prior, and informed consent), or water-scarce zones.[31]
- Monitor hydrogen leakage, certify carbon intensity, and promote circularity by integrating recycling and secondary recovery of critical minerals and clean energy equipment.[32]
- Require funded mine closure and rehabilitation plans from the start of operations.[33]

[28] See for example Global Sustainability Standards Board (2024). *GRI 14: Mining Sector 2024*.
[29] See for example Villagrasa, D. (2022). Green Hydrogen: Key success criteria for sustainable trade & production.
[30] See for example Global Sustainability Standards Board (2024). *GRI 14: Mining Sector 2024*.
[31] See for example IGF (2023). *Mining policy framework*..
[32] See for example UNIDO (2024). *Green Hydrogen for Sustainable Development. A policy toolkit for developing countries.*
[33] See for example IGF (2023). *Mining policy framework*.

BOX 2. CHILE'S MINING SECTOR: INTEGRATING RENEWABLE ENERGY AND WATER DESALINATION

Chile is the world's largest copper producer, with the mining sector accounting for a significant share of national exports and energy use. Historically, operations have depended on fossil-fuel-based electricity and intensive freshwater withdrawals, especially in the arid Atacama Desert. This created dual challenges: reducing greenhouse gas (GHG) emissions and addressing severe water scarcity.

In line with Chile's nationally determined contributions, the mining industry has accelerated its shift from coal and oil to renewable energy, especially solar and wind. By 2021, 44% of the sector's electricity demand was already met by low-emission sources.

Freshwater stress in northern Chile has driven large-scale investments in seawater desalination and direct use of untreated seawater. Mining companies have constructed pipelines and desalination plants to supply operations, reducing dependence on scarce continental freshwater. National policies encourage this shift as part of both climate change adaptation and water security strategies.

Integrating renewables and desalination is not just a technical solution but a governance challenge requiring strong climate policies, clear water rights, and stakeholder engagement. Chile's government has aligned mining decarbonisation with national climate goals and energy policies, encouraging companies to disclose mining-sector GHG emissions and set reduction targets.

Source: IGF (2024). *Decarbonization of the Mining Sector: Case Studies on the Role of Mining in Nationally Determined Contributions in Chile, Indonesia, and South Africa*.

Principle 3. Facilitate inclusive community partnerships

Communities should be genuine partners in decision-making throughout the project life cycle, and they should equitably share in the social and economic benefits that resource projects generate.

Key actions:

- Respect the collective and individual rights of Indigenous Peoples, as enshrined in the United Nations Declaration on the Rights of Indigenous Peoples.[34]
- Obtain free, prior, and informed consent before granting concessions, and throughout project life cycles.[35]
- Provide fair benefit-sharing through defined mechanisms such as community development agreements, royalties, equity participation, or local development funds.[36]
- Ensure that benefits extend beyond compensation to include employment, skills, infrastructure, and energy access. See example of the Maru a Mokopane project in Box 3.

[34] United Nations (2007). *United Nations Declaration on the Rights of Indigenous Peoples*.
[35] See for example Initiative for Responsible Mining Assurance (IRMA). *Standards*.
[36] See for example IGF (2023). *Mining policy framework*; UNIDO (2025). UNIDO's FairShare Programme; UNDP (2025). *Navigating the currents of green hydrogen: Towards a human development-centred framework*.

- Establish grievance mechanisms that are accessible to marginalised groups, including women, Indigenous Peoples and rural communities..[37]
- Ensure that service delivery, infrastructure, and social programmes are integrated into national and local development plans, so they continue after mine closure, avoiding over-reliance on companies..[38]

BOX 3. SOUTH AFRICA: LEVERAGING MINING INVESTMENTS FOR DIGITAL INCLUSION

Launched in 2017, the Maru a Mokopane project is a digital inclusion initiative by Ivanplats' Platreef Mine in Mokopane, Limpopo Province, South Africa. The project established around twenty free Wi-Fi hotspots in schools, clinics, and other community hubs surrounding the mine, giving thousands of local residents internet access.

As of 2024, the platform had attracted more than 30,400 registered users, with women accounting for about 42% of participants – an important milestone in narrowing the gender digital divide in rural mining communities. To support uptake, the mine contracted and trained 40 local young people as "digital ambassadors", responsible for assisting residents with registration, basic digital skills, and effective use of the platform.

Beyond internet access, Maru a Mokopane functions as an interactive community engagement portal. Residents can access and apply for job vacancies, bursaries, and procurement opportunities linked to the mine; browse a local business directory; and send feedback or raise concerns directly with the company. By 2024, over 7,400 CVs had been uploaded through the system, with women submitting more than 40% of applications. The portal is not just a communication tool but a gateway to employment, enterprise, and education.

The programme has proven particularly valuable for young people and women, who often face barriers to entering formal labour markets and digital economies. While sustainability challenges remain, this initiative demonstrates how mining investments in digital infrastructure can help to promote inclusive development.

Source: IGF (2024). *Leveraging Technologies for Gender Equality in Mining Communities. Case studies from the Democratic Republic of the Congo, South Africa, and Peru*.

[37] See for example OECD (2016). *OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas*: Third Edition. Paris: OECD Publishing; Global Sustainability Standards Board (2024). *GRI 14: Mining Sector 2024*.

[38] See for example IGF (2023). *Mining policy framework*; United Nations Economic Commission for Europe (2022). *United Nations Resource Management System. Principles and requirements*. Geneva; UNIDO (2025). UNIDO's FairShare Programme.

Principle 4. Strengthen governance, transparency, and accountability

Responsible trade depends on full transparency and accountability, requiring clear disclosure of social, environmental, and economic impacts, payments to governments, and due diligence practices across the supply chain.

Key actions:

- Strengthen local and regional government capacity to regulate, enforce, and deliver services..[39]
- Embed supply chain transparency into national governance frameworks by aligning disclosure requirements with international standards, such as GRI 14: Mining Sector, the OECD Due Diligence Guidance for Responsible Supply Chains, and the Extractive Industries Transparency Initiative (EITI) (see Box 4).
- Require independent, accredited audits for mines, hydrogen plants, and trading intermediaries..[40]
- Apply sanctions for non-compliance, including suspension of certification or export rights..[41]
- Strengthen permitting and licensing processes with clear, transparent criteria..[42]
- Establish anti-corruption safeguards in contracts and procurement..[43]

[39] See for example IGF (2023). *Mining policy framework*; UNIDO (2024). *Market Assessment on Critical Minerals Innovation in Developing Countries*.
[40] See for example Fairtrade (n.d.). *Gold miners – Where does our gold come from?*
[41] See for example IGF (2023). *Mining policy framework*; EITI (n.d.) *Policy priorities*.
[42] See for example United Nations Economic Commission for Europe (2022). *United Nations Resource Management System. Principles and requirements*. Geneva.
[43] See for example Standards Board (2024). *GRI 14: Mining Sector 2024*; EITI (n.d.) *Policy priorities*.

BOX 4. EITI: TRANSPARENCY AND ACCOUNTABILITY IN THE EXTRACTIVE SECTOR

The Extractive Industries Transparency Initiative (EITI) was established in 2003 as a global standard to improve transparency in oil, gas, and mining. By becoming a member of EITI, countries commit to disclosing information along the extractive industry value chain. Through participating in EITI, more than fifty countries have agreed to a common set of rules governing what has to be disclosed, and when.

EITI requires participating countries to make public:

- their legal and institutional framework – describing the legal framework and fiscal regime governing the extractive industries
- licences and contracts – clarifying who has been granted the right to extract resources from community lands
- beneficial ownership – revealing who ultimately profits from extractive companies, including hidden or foreign shareholders
- payments and revenue – showing how much companies pay in taxes, royalties, and fees, and how much governments receive.

Implementation is overseen by multi-stakeholder groups in each country, including civil society and, increasingly, representatives of Indigenous Peoples and community-based organisations.

EITI demonstrates how mandatory disclosure of extractive sector information can shift the power dynamics, giving citizens and communities the tools to hold companies and governments accountable. When combined with capacity-building for civil society, EITI can help to reduce corruption, strengthen governance, and improve the fairness of mining and resource revenue management.

Source: EITI (2023). The EITI Standard 2023.

Principle 5. Promote inclusive and sustainable industrialisation

Producer countries should derive lasting benefits from their mineral resources by pursuing value addition and long-term development, supported by fair and equitable global partnerships.

Key actions:

- Support local value creation through skills development, technical assistance, and technology transfer..[44] Box 5 illustrates how Namibia included measures to increase local value creation in its Minerals Beneficiation Strategy.

[44] See for example UNIDO (2024). *Green Hydrogen for Sustainable Development. A policy toolkit for developing countries.*

- Define clear mechanisms for equitable partnerships, including joint ventures, co-financing, and technology-sharing agreements to address power imbalances between producer and consumer countries.[45]
- Leverage government procurement to stimulate domestic markets and complement it with international financing mechanisms.
- Strengthen international governance through bilateral, plurilateral, and multilateral initiatives, including certification, tracking, and oversight systems for sustainable supply chains.[46]

BOX 5. NAMIBIA: LEVERAGING CRITICAL MINERALS FOR INCLUSIVE INDUSTRIALISATION

Namibia is positioning itself as a leader in sustainable mineral development and renewable energy innovation. With abundant solar and wind resources, coupled with deposits of lithium, cobalt, manganese and rare earth elements, the country recognises the strategic opportunity to leverage its natural endowments for economic diversification and inclusive industrialisation.

Key policies adopted by the country in this area include the Minerals Beneficiation Strategy (2021), which seeks to increase local value addition, create jobs, and attract foreign investment. Related measures include tax exemptions, special economic zones, and, since 2023, an export ban on unprocessed critical minerals such as lithium, cobalt, graphite, and rare earths. This is intended to encourage domestic refining and processing, though policymakers remain mindful of the possible risks to investment flows.

Namibia's Green Hydrogen Programme is a government-led initiative to develop Namibia's green hydrogen and derivative industries, including green ammonia, green iron, and related infrastructure. In April 2025 the country inaugurated industrial facilities to produce iron with zero emissions.

Namibia has also established several financing mechanisms to reinvest mining revenue and stimulate green growth, such as the Minerals Development Fund, backed by proceeds from mining royalties. It channels investment into mid and downstream segments of the minerals sector.

Strategic collaboration further reinforces Namibia's ambitions. The Namibia–EU Strategic Partnership on Raw Materials Value Chains and Renewable Hydrogen (2022) supports capacity building, skills development, and research on mineral processing and circularity. In addition, in 2023 Namibia and Japan signed a joint statement on mining sector cooperation, emphasising technology transfer and sustainable practices.

Source: Namibia Green Hydrogen Programme (2025). Website; UNIDO (2024). Market Assessment on Critical Minerals Innovation in Developing Countries.

[45] See for example UNDP (2025). *Navigating the currents of green hydrogen: Towards a human development-centred framework*.
[46] See for example UNIDO (2024). *UNIDO announces launch of Global Alliance for Responsible and Green Minerals in cooperation with Saudi Arabia*; UNIDO (2024). *Market Assessment on Critical Minerals Innovation in Developing Countries*.

5. Conclusion

Green hydrogen has the potential to play a transformative role in the global energy transition, yet its large-scale deployment depends on secure, sustainable, and ethical supplies of critical minerals. Developing and least developed countries are central to this value chain, providing the majority of the minerals required for electrolyser technologies. This reality presents both opportunities for inclusive industrialisation and risks of exploitation, environmental harm, and inequitable benefit-sharing.

The principles set out in this policy brief provide a framework to address these risks while ensuring that the transition to clean energy technologies advances broader sustainable development goals. By upholding decent work, minimising environmental and social impacts, fostering inclusive community partnerships, strengthening governance, transparency, and accountability, and enabling value addition through fair global partnerships, stakeholders can create resilient and responsible supply chains.

Delivering on this vision will require improved governance that ensures coordinated action across governments, industry, civil society, and international organisations. This means embedding human rights and environmental safeguards into mining, energy, and trade policies, while aligning international trade agreements and investment frameworks with sustainability and just transition objectives.

It also calls for initiatives that support the development of industrial capabilities, ensuring that more value is captured domestically. Mobilising finance and de-risking mechanisms will be essential. At the same time, advancing robust standards, traceability, and certification through international cooperation is critical to creating transparent and responsible supply chains.

Finally, policies should prioritise gender equality, community participation, and fair benefit-sharing by promoting inclusive decision-making processes, implementing targeted programmes, and investing in skills development initiatives that enable all groups to contribute to, and benefit from, the transition.

Taken together, transparent governance, robust standards, and equitable partnerships can help to ensure that the promise of green hydrogen—and other clean energy technologies—extends beyond decarbonisation, contributing to long-term prosperity, justice, and sustainability in both producer and consumer countries.

Appendix A. Review of responsible and ethical trade frameworks

Name	Organisation(s)	Key insights
Navigating the Main ESG Standards and Frameworks in the Mining Industry.[47]	Anthesis	• Harmonise mining standard benchmarks to simplify compliance and improve sustainability outcomes. • Adopt consolidated standards to reduce complexity and enhance accountability. • Use third-party verification for ESG compliance to promote continuous improvement. • Prioritise fair wages, human rights, and community development alongside environmental responsibility.
Extractive Industries Transparency Initiative (EITI).[48]	EITI	• Encourage countries to join EITI, committing to transparent disclosure across the extractive value chain. • Leverage the EITI Standard, agreed upon by over fifty countries, to establish consistent rules on the timing and scope of required disclosures, enhancing accountability and governance in mineral supply chains. • Seven areas of EITI requirements: oversight by the multi-stakeholder group; legal and institutional framework, contracts and licences; exploration and production; revenue collection; revenue management and distribution; social and economic spending; and outcomes and impact.
Gold miners – Where does our gold come from?.[49]	Fairtrade	• Adopt standards similar to the Fairtrade Gold Standard, which ensures fair wages, guarantees minimum prices for products, and mandates health and safety regulations in mining operations. • Implement strict guidelines to eliminate child labour, ensure women's rights, and protect the environment, including water sources and forests, in line with best practices. • Use independent audits, like those by FLOCERT (the social auditing and certification body for Fairtrade), to ensure mines meet the required standards for responsible mining, including the safe handling of chemicals and promoting workers' wellbeing.

[47] Kraft, B. and Hendry, J. (2024). *Navigating the Main ESG Standards and Frameworks in the Mining Industry*.
[48] EITI (n.d.) *Policy priorities*.
[49] Fairtrade (n.d.). *Gold miners – Where does our gold come from?*

Name	Organisation(s)	Key insights
Trade in Minerals Critical for Climate Transitions and the Green Economy: Developing Country Perspectives and Pathways for International Cooperation.[50]	Forum on Trade, Environment and the SDGs (TESS), UN Trade and Development (UNCTAD), UNEP (UN Environment Programme)	• Scale up critical mineral production to meet rising demand, ensuring supply security. • Support industrial capacity and reduce export dependency, especially in Africa, to integrate into ethical supply chains. • Focus on partnerships that enhance investment, transparency, skills, and technology transfer, such as the EU Global Gateway and Minerals Security Partnership. • Use frameworks like the UN Resource Management System (UNRMS) for sustainable practices, transparency, and circularity in mineral extraction. • Facilitate market access by aligning with key frameworks.
Action Partnerships.[51]	Global Battery Alliance (GBA)	• Adopt standards used by the GBA Battery Passport to ensure transparent, verified reporting on sustainable practices throughout the battery life cycle. • Promote sustainable practices across the value chain – sourcing, processing, transport, and recycling – to minimise environmental harm and respect human rights. • Leverage batteries to expand energy access in emerging economies and support a circular battery economy to reduce reliance on raw materials while addressing the health risks from informal recycling. • GBA guiding principles: establish a circular battery value chain as a major driver to achieve the Paris Agreement; establish a low-carbon economy in the value chain; create new jobs and additional economic value; and safeguard human rights and economic development consistent with the UN Sustainable Development Goals.
GRI 14: Mining Sector 2024.[52]	Global Sustainability Standards Board	• Adopt gender-specific human rights' due diligence, as well as gender-responsive corporate policies and codes of conduct in the workplace. • Report gender-disaggregated data. • Assess and report mine-site-level impacts, including those related to closure and rehabilitation of operational sites.

[50] TESS, UNCTAD, UNEP (2024). *Roundtable: Trade in Minerals Critical for Climate Transitions and the Green Economy: Developing Country Perspectives and Pathways for International Cooperation*.
[51] GBA (n.d.). *Establishing a Sustainable and Responsible Battery Value Chain.*
[52] Global Sustainability Standards Board (2024). *GRI 14: Mining Sector 2024*.

Name	Organisation(s)	Key insights
		• Engage local communities. • Report emergency preparedness and response plans. • Report the management and evaluation of the occupational health and safety performance, including ensuring the provision of gender-appropriate personal protective equipment for workers and processes to prevent and address workplace gender-based violence. • Set up procedures to address the risks and impacts of corruption. • Work collaboratively with the mining industry and institutions of academic and vocational education to develop curricula consistent with current and future local and national mining needs.
Green Hydrogen: Key success criteria for sustainable trade & production.[53]	Heinrich Böll Stiftung, Brot für die Welt	• Develop national strategies; for example, exporting countries should create GH2 roadmaps aligned with energy plans, ensuring strong social and environmental standards. • Prioritise environmental safeguards; for example, implement measures to prevent hydrogen leakage, certify carbon footprints, minimise water use, avoid biodiversity-rich sites, and promote recycling. • Enhance social benefits; for example, involve communities from the start, ensure fair land negotiations, provide training and local energy access, and integrate human rights and social standards in procurement. • Support GH2 market growth; for example, close the price gap with fossil hydrogen and promote international standardisation for certification and tracking. • Strengthen governance; for example, use bilateral, plurilateral, or multilateral policies to set high standards, with careful consideration of time and market fragmentation.
IGF Mining Policy Framework.[54]	Intergovernmental Forum on Mining, Minerals, Metals, and Sustainable Development (IGF)	• Establish an institutional framework that involves robust monitoring, enforcement, and accountability mechanisms. • Establish fiscal mechanisms to enable mining communities to benefit financially from mining activities. • Adopt legal and regulatory frameworks and guidance documents for the closure of mining sites. • Develop appropriate strategies for different types of artisanal and small-scale mining to integrate operators into the formal economy and legal system to help manage their impacts.

[53] Villagrasa, D. (2022). Green Hydrogen: Key success criteria for sustainable trade & production.
[54] IGF (2023). *Mining policy framework*.

Name	Organisation(s)	Key insights
Core labour standards.[55]	International Labour Organization (ILO)	• Freedom of association and the right to collective bargaining. • Elimination of forced or compulsory labour. • Abolition of child labour. • Elimination of discrimination in employment and occupation.
Initiative for Responsible Mining Assurance (IRMA).[56]	IRMA	• Establish clear benchmarks for responsible mining at the industrial scale, guided by independent audits to ensure accountability. • Require mining sector participants to take immediate steps towards responsible practices, such as initiating audits within one year of joining relevant initiatives. • Ensure adherence to established standards in business integrity, social responsibility, environmental responsibility, and planning for positive legacies, to ensure sustainable and ethical practices across the supply chain.
OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas.[57]	Organisation for Economic Co-operation and Development (OECD)	• Encourage companies to respect human rights and avoid exacerbating conflicts when sourcing minerals, particularly in high-risk or conflict-affected areas, to support sustainable and equitable development. • Support companies in adopting the 5-Step Framework for Risk-Based Due Diligence to strengthen responsible sourcing: 1. Establish strong company management systems; 2. Identify and assess risk in the supply chain; 3. Design and implement a strategy to respond to identified risks; 4. Carry out independent third-party audit of supply chain due diligence at identified points in the supply chain; and 5. Report on supply chain due diligence. • Collaborate with stakeholders, including the OECD, UN, professional associations, financial institutions, and civil society, to broadly distribute and encourage the adoption of responsible sourcing guidance across sectors.

[55] ILO Declaration on Fundamental Principles and Rights at Work, 1998 (revised 2022).
[56] IRMA (n.d.). *Standards*.
[57] OECD (2016). OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas: Third Edition. Paris: OECD Publishing. https://doi.org/10.1787/9789264252479-en.

Name	Organisation(s)	Key insights
Responsible Minerals Initiative (RMI).[58]	RMI	• Providing companies with tools to improve compliance and ensure responsible sourcing of critical minerals, particularly from high-risk areas. • Encouraging dialogue and collaboration through umbrella organisations like the RMI to shape responsible sourcing practices across the sector. • Implementing robust due diligence processes, including using tools like the Conflict Minerals Reporting Template and Cobalt Reporting Template, to track and report on supply chains. • Ensuring that business practices align with global standards to support responsible mineral sourcing and foster positive social and economic development.
Responsible Cobalt Initiative.[59]	The Responsible and Ethical Private Sector Coalition against Trafficking (RESPECT)	• Encourage companies within the supply chain to collaborate to mitigate social and environmental issues, such as addressing child labour, in the extraction of critical minerals like cobalt. • Ensure that both downstream and upstream companies adhere to the OECD and Chinese Due Diligence Guidelines for mineral supply chains, fostering transparency and improved governance in cobalt sourcing. • Work with governments, civil society, and local communities in high-risk areas to effectively address cobalt supply chain risks and challenges. • Develop consistent communication channels to report progress and results to communities, miners, and the public, aligning objectives with other stakeholders for cohesive efforts.
United Nations Resource Management System (UNRMS).[60]	United Nations	• Principles: (i) state rights and responsibilities in the management of resources; (ii) responsibility to the planet; (iii) integrated management of resources; (iv) social engagement; (v) service orientation for the use and reuse of resources; (vi) comprehensive resource recovery; (vii) value addition; (viii) circularity; (ix) health and safety; (x) innovation; (xi) transparency; and (xii) continuous strengthening of core competencies and capabilities.

[58] RMI (n.d.). *Responsible Minerals Initiative*.
[59] RESPECT (2016). *Responsible Cobalt Initiative (RCI) - Chinese Chamber of Commerce for Metals, Minerals & Chemicals (CCCMC) Importers & Exporters and the Organisation for Economic Co-operation and Development (OECD).*
[60] United Nations Economic Commission for Europe (2022). *United Nations Resource Management System. Principles and requirements*. Geneva.

Name	Organisation(s)	Key insights
3P framework for green hydrogen.[61]	United Nations Development Programme (UNDP)	People • Ensuring additionality, with the improvement of grid connections and infrastructure build-out. • Incentives for the local provision of energy to local communities as part of hydrogen projects. • Provision for training, up-skilling, and hiring the local labour force across the value chain. • Clear fiscal and taxation frameworks to ensure sustainability of large-scale green hydrogen projects. Planet • Strong environmental appraisal capabilities to align green hydrogen projects with locally defined environmental priorities. Prosperity • Integrating green hydrogen in broader development policy with clear and well-defined objectives. • Creating and relying on technology foresight units to anticipate potential disruptions and identify opportunities for local linkages in the hydrogen value chain. • Cautious experimentation through pilot projects and phased investments.
Achieving a Green Hydrogen transition built on equity and consensus.[62]	United Nations Industrial Development Organisation (UNIDO)	• Ensure equitable access to electricity and reduce dependence on fossil fuels. • Use GH2 to produce local green goods, preserving domestic water and offsetting deficits with renewable freshwater trade, reducing export-related environmental impacts. • Balance land use to prevent competition with agriculture. • Reduce resource use in solar panels and electrolysis and use GH2 risk assessments to control leaks and protect biodiversity. • Engage local communities and stakeholders in decision-making for equitable benefits.
FairShare Programme.[63]	United Nations Industrial Development Organisation (UNIDO)	Key areas of impact: • Fair value distribution. Ensuring that the economic benefits of global trade are shared more equitably across global supply chains. • Better skills, better jobs. Empowering workers in producer countries with the skills needed for meaningful and sustainable employment.

[61] UNDP (2025). *Navigating the currents of green hydrogen: Towards a human development-centred framework*. UNDP.
[62] Fokeer, S., Sievernich, J. and Schwager, P. (2022). Achieving a Green Hydrogen transition built on equity and consensus. *Industrial Analytics Platform*, November.
[63] UNIDO (2025). UNIDO's FairShare Programme.

Name	Organisation(s)	Key insights
		• Green supply chains. Promoting environmentally sustainable practices by integrating circular economy principles, resource efficiency, and clean technologies into supply chains. • Transparency and resilience. Ensuring greater transparency, accountability, and resilience in international trade.
Green Hydrogen for Sustainable Industrial Development.[64]	United Nations Industrial Development Organisation (UNIDO)	• Fostering inclusive technology advancement and sustainable energy generation. • Stimulating market creation and demand for green goods. • Formulating comprehensive, long-term strategies for the transport of GH2 with a focus on efficient and standardised regulations. • Global partnerships, international collaboration and financing strategies for GH2.
Global Alliance for Responsible and Green Minerals in cooperation with Saudi Arabia.[65]	United Nations Industrial Development Organisation (UNIDO)	• Support the creation of a global alliance, led by UNIDO and international partners, to promote socially and environmentally responsible mining, with an initial focus on critical mineral-producing regions in Africa, Asia, and Latin America. • Develop international standards and a certification system to establish sustainable practices in critical mineral supply chains, assisting countries in effective policy implementation. • Foster skills development and knowledge exchange among participating countries and industry stakeholders to build capacity in responsible mining. • Coordinate policies, technology, and funding within the alliance to ensure a fair and sustainable mining sector that benefits all. • Encourage industrialisation and local value creation in developing countries, with initiatives targeting areas such as energy access, water management, and food security. • Collaborate with UNIDO to support the industrial development goals of developing nations, with a focus on least developed and landlocked countries, to promote sustainable and inclusive growth.

[64] UNIDO (2024). *Green Hydrogen for Sustainable Development. A policy toolkit for developing countries.*
[65] UNIDO (2024). *UNIDO announces launch of Global Alliance for Responsible and Green Minerals in cooperation with Saudi Arabia*.

Name	Organisation(s)	Key insights
Market Assessment on Critical Minerals Innovation in Developing Countries.[66]	United Nations Industrial Development Organisation (UNIDO)	• Enhance countries' institutional, policy, regulatory, data, and R&D capacities in the mid- and downstream segments of critical minerals value chains. • Create and bridge global multi stakeholder collaboration platforms. • Industry-led initiatives like mining associations and hubs should be encouraged and expanded as important mechanisms for a unified approach to innovation. • Enabling regulatory and financial conditions need to be put in place to facilitate technology transfer of existing mid- and downstream critical minerals technologies.
High demand for energy-related critical minerals creates supply chain pressures.[67]	World Trade Organisation (WTO)	• Support open trade policies to ensure sustainable access to critical minerals, facilitating a global low-carbon transition.
International trade and green hydrogen.[68]	WTO, International Renewable Energy Agency (IRENA)	Five actions that policymakers should consider: • Addressing trade barriers, for example reducing tariffs and non-tariff barriers on GH2, electrolysers, and related products. • Developing national quality standards aligned with international frameworks, promoting standardised carbon measurement and verification methods. • Implementing targeted environmental subsidies, eliminating fossil fuel subsidies, and bridging the cost gap between GH2 and fossil fuels. • Using government procurement to drive demand for low-carbon products, promoting innovation, and supporting collaborative policies to achieve economies of scale. • Strengthening global partnerships, supporting technology development, offering technical assistance, and providing aid to developing countries to build capacity for GH2 adoption.

[66] UNIDO (2024). *Market Assessment on Critical Minerals Innovation in Developing Countries*.
[67] Snoussi-Mimouni, M. and Avérous, S. (2024). *High demand for energy-related critical minerals creates supply chain pressures*.
[68] WTO and IRENA (2023). *International trade and green hydrogen: Supporting the global transition to a low-carbon economy*. Geneva and Abu Dhabi: World Trade Organization and the International Renewable Energy Agency.

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This report was delivered through IfM Engage, the knowledge-transfer arm of the Institute for Manufacturing (IfM), University of Cambridge.

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