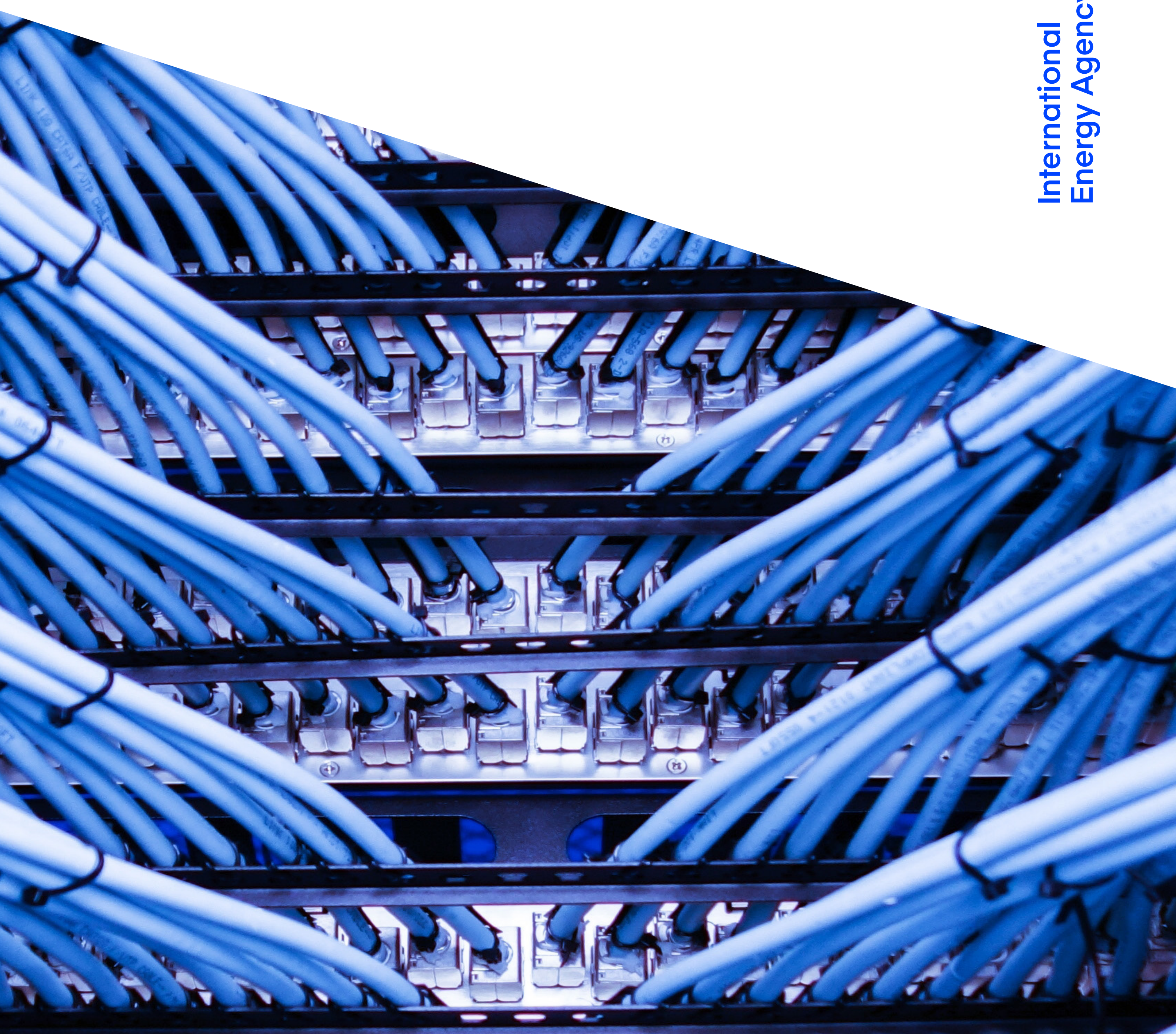
Clean Energy Technology Supply Chain Data

Challenges and potential solutions



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Abstract

Energy security in the Age of Electricity is inextricably linked to securing the supply chains for clean energy technologies and the equipment and materials used to manufacture them. As countries continue to pursue energy transitions and to direct investments to these technologies, guided by industrial strategies, a detailed understanding of their supply chains has an essential role to play. The availability of good-quality, timely data is crucial to gaining this understanding and to identifying and addressing supply chain vulnerabilities.

This report is provided as an input to the discussions taking place as part of the Global Clean Power Alliance Supply Chains Mission – an initiative established by the Government of the United Kingdom to advance practical solutions to strengthen clean power supply chains. This report addresses the data component of this initiative and explores the challenges – and potential solutions – to the paucity of granular and timely data associated with clean energy technology supply chains.

Acknowledgements

This report was prepared by the Energy Data Centre and Energy Technology Policy Division of the International Energy Agency. The study was designed and directed by Zuzana Dobrotkova, Head of Annual Energy Data and Statistics. Peter Levi, Head of the Technology Supply Chain Unit, provided strategic guidance and input to this work. Principal contributors were Jack Jaensch and Faidon Papadimoulis. Valuable comments and feedback were provided by senior management, including Nick Johnstone and Timur Gül.

Lizzie Sayer edited the manuscript. Per-Anders Widell provided essential support throughout the process. Thanks also to the IEA Communications and Digital Office for their help in producing the report, particularly to Poeli Bojorquez, Astrid Dumond and Isabelle Nonain-Semelin.

The work benefited from financial support provided by the Government of the United Kingdom, and from discussions during two technical workshops hosted by the IEA in 2025 convening several government representatives and relevant international organisations.

Several experts from outside of the IEA provided valuable input, commented and reviewed this report and activity participated in the two technical workshops. They include: Andrea Andrenelli (Trade and Agriculture Directorate, OECD); Jane Chandler (United Kingdom, Department for Energy Security and Net Zero); Fernando de Oliveira (Trade and Agriculture Directorate, OECD); Brigette Demerais (Natural Resources Canada); Gael Grooby (World Customs Organization); Natalia Hoffman Ramos (Brazil, Ministry of Mines and Energy); Birte Holst Joergensen (Technical University of Denmark); Premyslaw Kowalski (Trade and Agriculture Directorate, OECD); Atsushi Kurosawa (The Institute of Applied Energy, Japan); Sam Lowe (Australia, Department of Climate Change, Energy, the Environment and Water); Veronica Piatkov (Australia, Department of Climate Change, Energy, the Environment and Water); Simon Strickland (United Kingdom, Cabinet Office); Narayan Subramanian (Independent Consultant); Evdokia Tapoglou (European Commission, Joint Research Centre); Jacopo Tattini (European Commission, DG GROW); Robert Towers (United Kingdom, Department for Energy Security and Net Zero); Daniel Weaver (United Kingdom, Department for Energy Security and Net Zero).

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Executive summary

Energy security in the Age of Electricity is inextricably linked to securing the supply chains for clean energy technologies and the equipment and materials used to manufacture them. As countries continue to pursue energy transitions and make investments in the deployment and manufacturing of these technologies – guided by industrial strategies – a detailed understanding of their supply chains has an essential role to play.

The availability of good-quality, timely data is crucial to understanding clean energy technology supply chains and addressing vulnerabilities. Risks to supply chains can arise from interdependencies across technologies and between geographies, among other factors. Today, the available data shows that many clean energy technology supply chains are highly concentrated, and therefore vulnerable to potential disruptions caused both by human activity, such as trade restrictions and conflict, and by natural hazards – exacerbating risks to energy security.

High-quality, timely data on energy technology supply chains is essential for evidence-based policy making. This could include, for example, understanding which countries have undeveloped mineral resources that could be mined and refined competitively to satisfy future demand and diversify supply, or the potential to develop a competitive manufacturing base in a particular country to position it in a given clean energy supply chain. To reduce vulnerabilities in the supply chain, better data could help uncover a given country or industry's exposure to a particular trade partner for a given technology, or to a potential increase in price for a certain material or component. Such data could also help identify opportunities to increase strategic trade partnerships for a particular mineral, material component or technology.

There is currently no authoritative "one-stop-shop" source for energy technology supply chain data globally. Different data sources – some public and others proprietary – are needed to compose even a partial picture of the supply chains of interest, with varying degrees of quality and coverage. In addition, the clean energy technology supply chain is developing rapidly, and systems of data collection must be able to keep pace as technologies, resource availabilities and cost structures change over time.

Strengthening global supply chains for clean power is the goal of the Supply Chains Mission which was established by the United Kingdom in 2025 under the Global Clean Power Alliance (GCPA). The Mission aims to work with international partners to identify and deliver the changes needed to diversify clean power supply chains and resolve bottlenecks. This report supports the work of the Data pillar of the Mission by providing a high-level assessment of the current status of data relevant to clean energy supply chains and proposing a menu of possible actions to address data challenges, both at the national level and through international collaboration.

While this work is relevant for many countries, emerging markets and developing economies could particularly benefit. Better data could support strategic expansion of their footprint in clean energy technology supply chains, contributing to increased industrialisation and economic development. If successful, such expansion would also help to increase diversification of clean energy supply chains globally, strengthening the energy security of all countries.

Government action will be essential to improve the availability and quality of data on clean energy technology supply chains. Example measures include mandatory reporting and ensuring adequate staffing and resources for data collection and publication. While this has a cost, the investment in data collection required is small when compared to the benefits of the commercial investment and industrialisation it could enable, and of resulting improvements in energy security. The actions of individual governments, while essential, will be insufficient on their own. Given the global nature of how clean energy technology supply chains evolve, a holistic approach, drawing on international collaboration, will be needed to improve the current state of energy technology supply chain data.

There are many potential actions governments can take to address supply chain data challenges – the Supply Chains Mission can be a key forum in which to co-ordinate and prioritise. This report culminates in a set of suggested government actions as an input to the discussions taking place under the Supply Chains Mission. In the next 6 months, it is suggested that governments could map the entitles responsible for data collection activities domestically and designate responsibility for co-ordinating relevant efforts, as well as beginning to engage with international entities active in this space. In the next year, it is suggested that governments may wish to establish or enhance the regulatory framework supporting data collection activities nationally, and to establish collaborations on these activities with industry and academia across the world. If governments co-ordinate their actions, their efforts can be multiplied, and the challenges around supply chain data that this report identifies can be made more tractable.

Introduction

Clean energy technology supply chains[1] are gaining increasing attention from policy makers due to their importance for energy transitions, energy security and industrial development. However, the data used to track and understand clean energy supply chains – which is a crucial input to evidence-based policy making – is, in many cases, limited, incomplete, or of poor-quality.

This report provides an overview of data relevant to clean energy technology supply chains: its sources, characteristics and uses. The report also summarises the data quality issues encountered in the available data sources and the implications of those issues. The complexity of tracking certain types of data that cover resources spanning across many different supply chains, is also discussed. It concludes with a series of policy considerations, including a menu of potential actions to address the issues identified.

The report is provided as an input to the discussions taking place under the Data pillar of the Supply Chains Mission launched in 2025 through the Global Clean Power Alliance (GCPA). The work under this pillar is guided by the belief that better data enables more effective policy analysis and decision-making, which in turn can strengthen energy security and industrial development, at the same time as supporting efforts to track progress in energy transitions.

Energy security risks are evolving

While much has changed since the oil crises of the 1970s first brought the issue of energy security into sharp focus, it remains a pressing concern for many countries. As energy systems become more electrified and more decentralised, the concept of energy security has expanded beyond its initial concentration on oil supply. Energy security now encompasses not only fuels but also clean energy technologies. These technologies use widely available and renewable resources, such as sunshine, wind and ambient temperature, which are inherently more secure than fossil fuels due to their universal accessibility.

The potential impacts of disruptions to fossil fuel and clean energy technology supply chains differ. For clean energy technologies, the potential bottlenecks and scarcity of supplies that could affect energy security are not related to the extraction and transport of fuels, but instead to the availability of materials and equipment used to generate, convert and use electricity. For fossil fuels, the

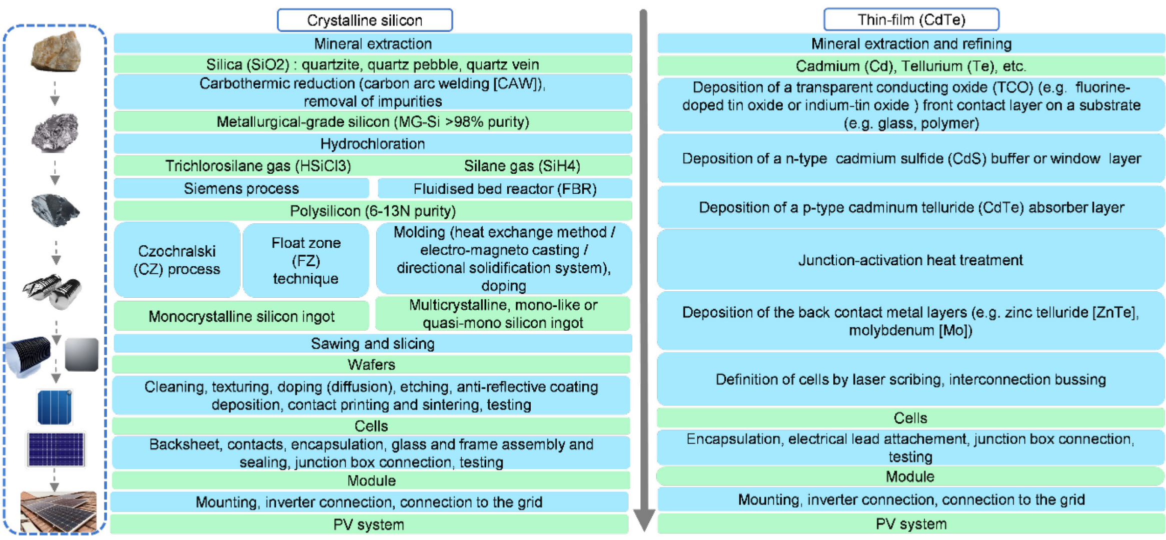
[1] In the context of this report, 'clean energy technology supply chains' refers broadly to a range of technologies, components and materials that underpin the Age of Electricity, including grid technologies and critical minerals.

impacts of supply disruptions can be felt by consumers in a matter of days. By contrast, disruptions to clean energy technology supply chains mostly affect the build-out of new facilities or the replacement of existing ones. However, as the world enters the Age of Electricity the centrality of these supply chains in considerations around energy security is only set to increase.

Clean energy technology supply chains are complex

Clean energy technology supply chains are generally less mature and more complex than fossil fuel supply chains, in which fuels are extracted, cleaned, refined, or otherwise processed and can then be directly traded as commodities. By contrast, clean energy technology supply chains consist of multiple steps, with inputs of materials, components and services involved at each stage, often encompassing dozens of minerals, metals, other materials and components (many of which have proprietary designs) each of which are often traded between multiple countries. Different design variants within a given technology category can imply substantial differences in supply chain arrangements, as can be seen in the examples of crystalline and thin-film solar PV systems (see Figure 1).

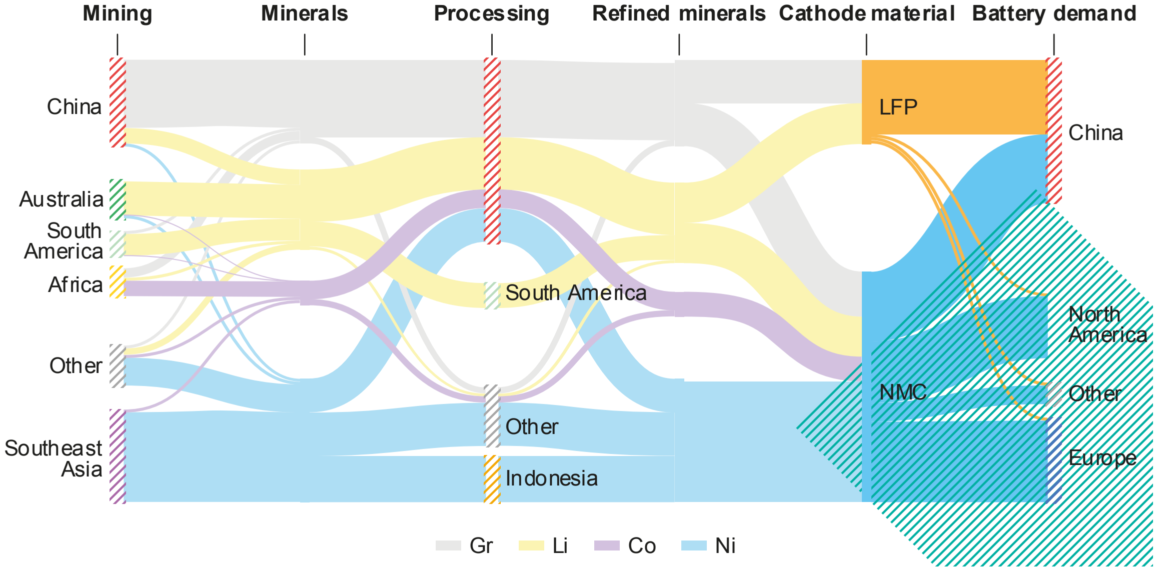
Figure 1. Simplified supply chain for crystalline silicon and thin-film solar PV systems



Source: IEA (2022), Special Report on Solar PV Global Supply Chains.

Clean energy technology supply chains tend to have a much greater reliance than fossil fuel supply chains on a wide variety of critical minerals, including rare earth elements (REEs[2]), copper, nickel, lithium, cobalt, manganese, graphite, silicon and platinum group elements. Figure 2 shows the prevalence of some of these minerals across the supply chains for producing electric vehicle (EV) batteries. As technologies progress rapidly, supply chains are subject to constant changes. For example, the metals used in batteries keep evolving based on their overall performance, as well as their availability and price on the market. In 2020, lithium nickel manganese cobalt oxide (NMC) batteries supplied over 90% of the electric car battery market globally, while lithium iron phosphate (LFP) batteries supplied less than 10%. However, by 2024, almost half of this market was supplied by LFP batteries, displacing, in part, chemistries based on nickel and cobalt. This shift was initially driven by high nickel and cobalt prices in 2021-2022, but continued even as mineral prices then declined, as a result of innovations that improved the energy density of LFP and increased price competition in the EV market.

Figure 2. Electric vehicle battery minerals' supply chain from extraction to end-use, by mineral value, 2023



Notes: Gr = graphite; Li = lithium; Co = cobalt; Ni = nickel; LFP = lithium iron phosphate; NMC = lithium nickel manganese cobalt oxide. Flows are scaled based on the economic value of a mineral or the combined value of minerals used in the cathode or electric vehicle battery. All flows are represented on a material price term.
Source: IEA (2025), The State of Energy Innovation 2025.

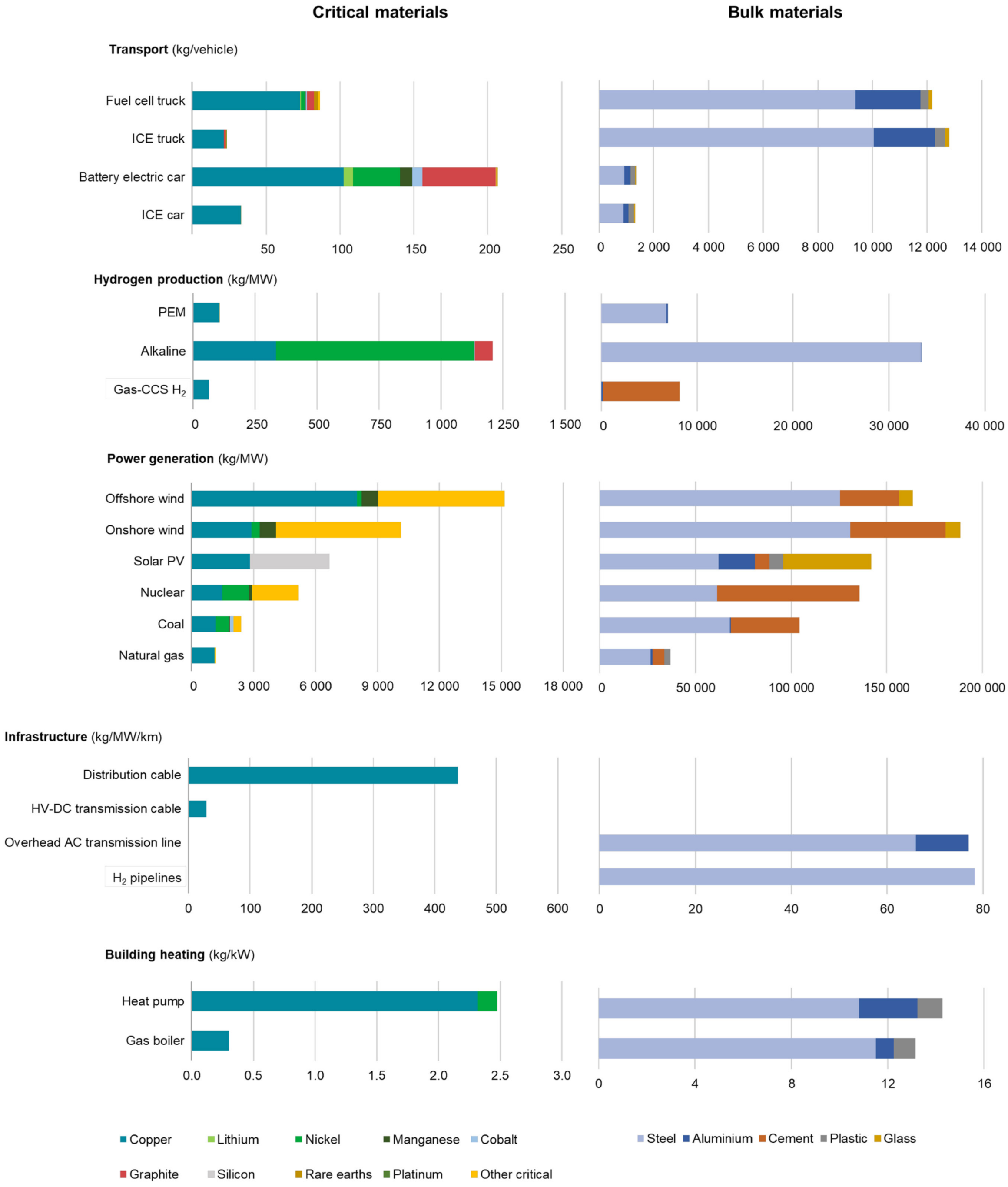
[2] REEs encompass 15 lanthanides (metallic chemical elements with atomic numbers 57–71), along with scandium and yttrium.

Clean energy supply chains use a vast array of different mineral and material resources, and their use varies by technology. Batteries require lithium, cobalt, manganese and nickel, while the magnets in some wind turbines and electric engines require REEs (Figure 3). Electricity networks, electric appliances and equipment and EVs all require copper. Electrolysers and fuel cells require nickel or platinum group metals, depending on the technology type. The quantities of critical minerals and other raw materials needed for clean energy technologies can be significant: Solar and wind generally require more steel, aluminium and, in some cases, cement per unit of capacity than fossil fuel-based generating technologies. For example, an onshore wind plant requires nine times more mineral resources than a gas-fired plant with the same capacity. For more analysis and modelling related to critical minerals and the global energy system, please see the IEA's Global Critical Minerals Outlook 2025.

The supply chains for clean energy technologies typically span across many different countries. In a globalised world with unevenly distributed resources, it is unrealistic for countries to seek to locate entire clean energy supply chains within their borders. Instead, to tap into the growing markets for clean energy technologies, countries are racing to position themselves in the supply chains for these technologies, including by devising industrial strategies in order to build or expand their market shares. The multiple steps in the complex supply chains for clean energy technologies present several potential opportunities for countries seeking to gain a strategic position. Many of these do not depend on the presence of a mineral deposit or the availability of other natural resources. Different policy measures can support the expansion of supply chains, such as overarching industrial strategies, targeted RD&D support, tax and duty exemptions, or more interventionist policies, such as subsidising the cost of energy or materials.

Energy security considerations related to clean energy technologies go beyond the risks to supply of physical assets. Deployment of clean energy technologies takes place in the context of increasing electrification, which brings with it new cyber security challenges related to the IT systems required to manage electricity generation, transmission, distribution and consumption. As digital controls, sensors and connected devices proliferate in order to integrate clean energy technologies into the system – and operate systems closer to their limits – exposure to cyber risk is growing in scale and complexity.

Figure 3. Global average raw material requirements for selected energy technologies, 2021



Note: While this figure depicts raw material requirements in 2021, these remain quite stable in time and have not changed significantly since then.
Source: IEA (2023), Energy Technology Perspectives 2023.

The complexity of clean energy technology supply chains means they encompass multiple different sources of vulnerability that could impact energy security:

- Undue dependence on a single producer, whether it be a country, a corporate entity or an individual facility.
- Maritime or other chokepoints in trading routes.
- Conflict, geopolitical instability, piracy, cyber-attacks or other risks stemming from human activity that can affect production and trade.
- Natural hazards and weather-related risks that can affect production and trade.
- Competition for materials or components with other sectors with higher willingness to pay, affecting costs and availability (for example defence, aerospace, medical equipment or electronics).
- ‘Dumping’ and other non-market practices that can affect the appetite for investment and future levels of supply.
- Very long permitting procedures preventing agile adjustments of supply chains.
- Complex frameworks for environmental and social standards, which can affect levels of compliance and the ability to document the acceptability of materials, components and final products. This includes the lack of traceability in critical mineral supply chains.
- A lack of substitutability or repairability with respect to a given mineral, material or component.
- A lack of appropriately skilled labour.
- Systematic limitations in access to the investment required to build-out processing and manufacturing facilities, such as in the case of several developing economies.

Many of these risks can be partially alleviated by policy choices made by governments, but the inverse is also true – certain policy choices may exacerbate risks. In this context, high-quality, up-to-date data are crucial inputs to evidenced-based policy design.

Geographical concentration poses risks

Supply chains are especially vulnerable to the risks associated with geographic concentration. This can lead to information asymmetries, inefficient pricing in the market and the exercising of market power, or other signs of market concentration. Concentration in a particular geography exacerbates other risks, such as lack of diversity in trading routes or vulnerability to natural hazards or human-caused risks.

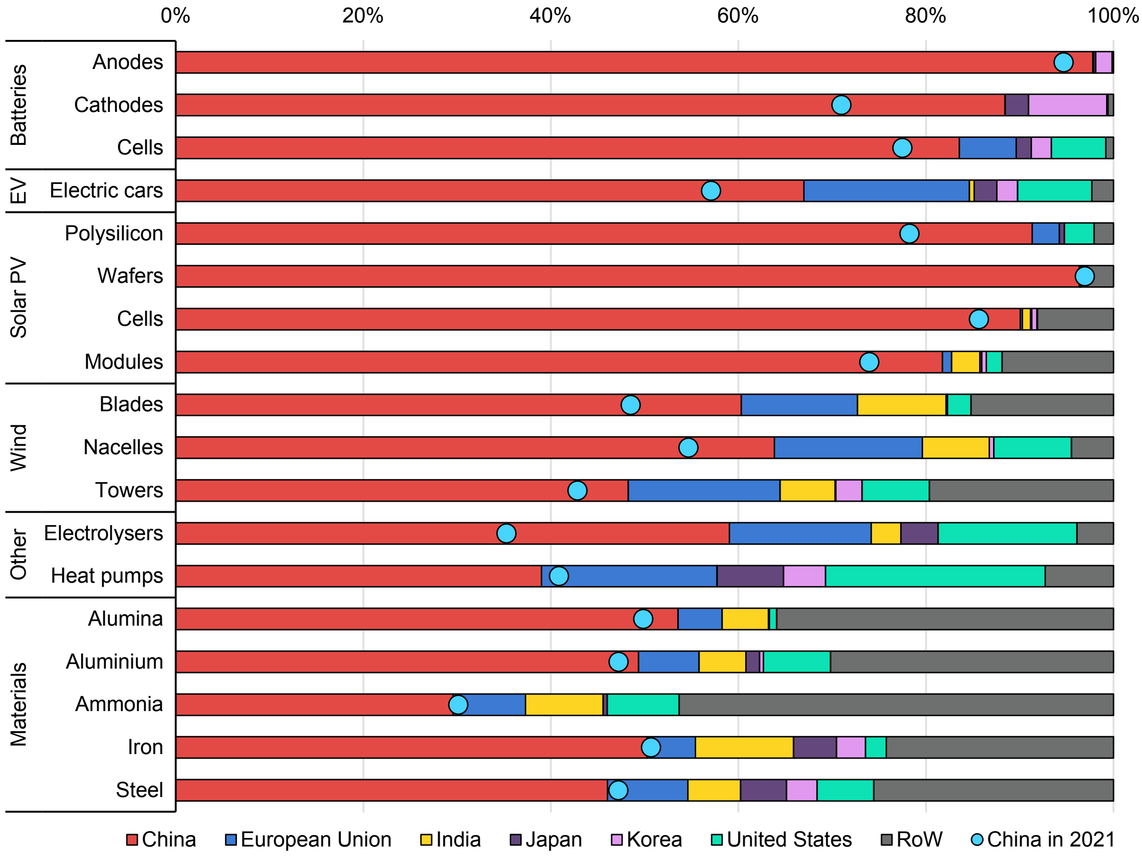
Concentration in one country or region can be a result of natural resource endowments for particular metals or minerals, as deposits can be highly concentrated. For example, over half of the world’s currently known cobalt reserves are located in the Democratic Republic of Congo. However, refining and other processing of metals and minerals also play a crucial role and can be even more concentrated than the deposits themselves.

Market concentration can result, in part, from the comparative advantage of certain regions that have abundant resources, but low production costs, policies that transfer costs from producers to taxpayers and certain measures that affect trade also contribute to concentration in the supply chain. The size of different economies also contributes to the concentration observed in different markets.

The downstream steps in supply chains tend to be less concentrated than those upstream. For example, in the solar PV supply chain, the People's Republic of China (hereafter, "China") accounts for more than 95% of global wafer production, whereas substantial shares of global cell and module production take place in Southeast Asia – albeit in many cases in factories owned by Chinese companies. Battery production is similarly more concentrated at the upstream steps (e.g. anode and cathode production) and less so at the downstream cell production step. In contrast, the manufacturing of the main components of wind turbines – nacelles, blades and towers – more often takes place in (or closer to) the deployment location. For more information on the manufacturing and trade of clean energy technologies, please see the IEA's Energy Technology Perspectives 2024.

Diversification is fundamental to efforts enhance energy security – this is as true for clean energy technology supply chains as it is for oil and gas. As the volume of international trade continues to grow for all goods worldwide, the risk of severe congestion and physical supply disruptions at chokepoints along the main shipping routes increases. These can be caused by geopolitical instabilities, natural hazards and weather-related events, piracy or accidents. Establishing alternative routes, for example by building new rail corridors, and strengthening diplomatic efforts to reinforce international agreements that facilitate new trading corridors, are crucial for improving the security of supply chains. See Chapter 5 of the IEA's Energy Technology Perspectives 2024 report for more analysis and information on maritime chokepoints.

Figure 4. Installed manufacturing capacity by country/region, 2023



Notes: RoW = Rest of World. "Electric cars" values are calculated based on 2023 production numbers, adjusted according to the utilisation rates of car assembly plants in the region.
Source: IEA (2024), Energy Technology Perspectives 2024.

Government policies – particularly trade and industrial policies – also have a big impact on security. Changes in tariffs, duties and other taxes can impact costs, prices and competitiveness, or even the overall financial viability of parts of supply chains, leading to delays or disruptions in deliveries, or a need to change suppliers. Controls and restrictions on exports are sometimes used as a geopolitical tool to preserve a dominant position in the market, or for other political goals. While this is not a new phenomenon and has been used in several strategic industries over many decades, a growing number of countries and regions are now taking an increasingly defensive position on trade (see Box 1). Timely trade and price data can help analysts to determine the impacts of different controls and restrictions, and better inform government policy responses.

Given their complexity, there are many more possible points of failure in clean energy supply chains than those of fossil fuels, as well as a wide range of different dependencies that need to be managed. One strategy being considered to hedge against the risks of supply disruptions is stockpiling, which is possible for certain critical minerals, but it comes at a cost. International collaboration can decrease these costs, for example through creating and co-ordinating stockpiles of selected critical minerals, as is being considered by the IEA's Critical Minerals Security Programme. New policies and industrial facilities to support recycling of critical minerals can also reduce supply risks as demand increases. IEA analysis shows that growth in new mining supply for critical minerals could be reduced by between 25% and 40% by mid-century by scaling up recycling. Other recent analysis indicates significant potential benefits from improved by-product recovery from mines.

Box 1. Recent export restrictions on clean energy supply chains

On 4 April 2025, the Chinese government introduced export controls on seven heavy rare earth elements (REEs), as well as all related compounds, metals and magnets. This caused export volumes to fall sharply in April and May, and many carmakers in the United States, Europe and elsewhere struggled to obtain permanent magnets needed for car production. Even after trade volumes recovered, rare earth prices in importing countries remained elevated – with European prices reaching up to six times those in China – impacting the cost-competitiveness of rare earth-based products manufactured outside China.

On 9 October 2025, the Ministry of Commerce of China announced further export controls on REEs and related products, equipment and technologies. The inclusion of "parts, components and assemblies", beyond the previous isolated controls on selected rare earth magnets and materials, could have a dramatic impact on global supply chains, as many strategic sectors, such as energy, automotive, defence, semiconductors, aerospace, industrial motors and AI data centres, rely on products and components containing the controlled Chinese REEs.

Moreover, the list of REEs subject to controls was expanded to include five additional elements – holmium, erbium, thulium, europium and ytterbium – on top of the seven elements initially restricted in April. The inclusion of holmium was particularly significant, as many permanent-magnet-makers had been revising their approach to replace the previously restricted rare earths with holmium since April 2025. New controls were also announced on a wide range of equipment for processing rare earths, including for milling, separation and refining.

China also announced major export controls on parts of lithium-ion battery supply chains, which were supposed to take effect from 8 November. The new controls expanded on previous measures to cover a much broader range of battery materials, technologies and equipment across multiple stages of the supply chain. This included battery cells and packs for high-performance applications, cathode precursors, an expanded scope for anode materials (including artificial graphite materials), broader coverage of lithium iron phosphate (LFP) cathode materials, and battery and material production equipment and technologies.

Such export controls on rare earths and on equipment for processing of rare earths could significantly undermine international efforts to diversify rare earth supply chains, refine raw materials and produce permanent magnets, resulting in slower development of strategic manufacturing and increased vulnerability to supply shocks.

On 30 October, after a high-level meeting between the leaders of the United States and China, a 1-year suspension of the implementation of China's new export controls was announced. Nevertheless, these developments underline the crucial importance of advancing diversification to ensure the long-term resilience of global supply chains.

Source: Based on IEA (2025) With new export controls on critical minerals, supply concentration risks become reality, with an update after 30 October 2025.

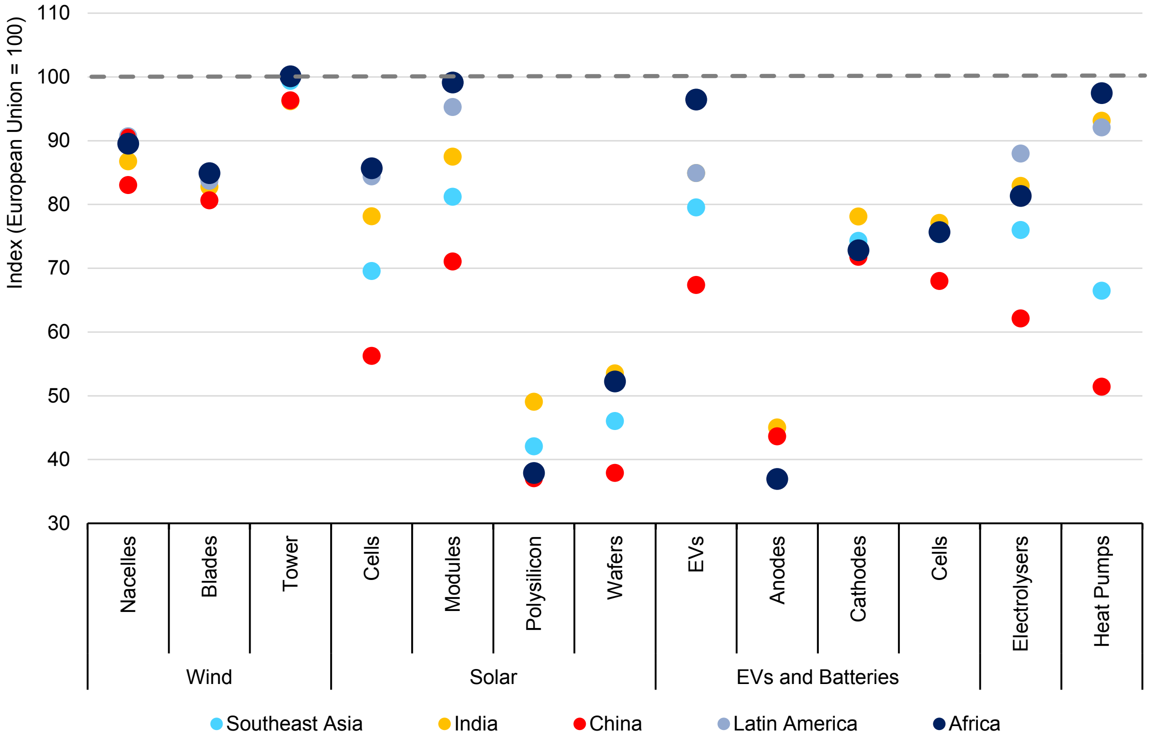
Economic opportunities exist

The global combined market for six key clean energy technologies – solar PV, wind, batteries, EVs, heat pumps and electrolysers – amounted to more than USD 700 billion in 2023. The lion's share of this global market is held by China, which accounted for nearly 60%, reflecting the extent of its domestic clean technology deployment. Advanced economies accounted for around one-third, while emerging economies other than China accounted for a much smaller share, at 5% in aggregate.

Continued increases in clean energy technology deployment and countries' efforts to diversify supplies thereof will create industrial opportunities across supply chains, and opportunities for strategic partnerships. The diversification of supply chains would improve overall energy security by reducing the concentration of production and exports, and therefore the pressure on particular supply routes. International collaboration, in particular between developed countries and emerging market and developing economies (EMDEs), in the form of joint ventures or other partnerships, could help support the transfer of industrial expertise for the development of new resources. This is already happening to some extent. For example, the northwestern and central regions of Namibia contain high-grade deposits of dysprosium and terbium – both REEs that are difficult to substitute – which are used to produce permanent magnets. Namibia is collaborating with Japan and the European Union to develop these resources, and over time the country could contribute to diversifying the global supply of REEs.

As well as helping with efforts to diversify supply chains, partnerships can also serve to enhance competitiveness. The lower cost of manufacturing in many EMDEs constitutes potential opportunities for these economies to take a step up the value chain from a role that is often focused around resource extraction and mining to one that is more active in the higher value-added steps further downstream, like material production and manufacturing (Figure 5). Improved manufacturing capabilities can also help accelerate domestic deployment of clean energy technologies by creating a more politically and socially durable link to the economic benefits of producing them. As with the diagnosis of security risks, identifying these industrial opportunities depends on access to robust data.

Figure 5. Theoretical cost of manufacturing clean energy technologies and components in selected regions and countries, relative to the European Union, 2023



Source: IEA (2025), Stepping Up the Value Chain in Africa: Minerals, materials and manufacturing.

The Supply Chains Mission

Strengthening global supply chains for clean power is the goal of the Supply Chains Mission launched in 2025 under the Global Clean Power Alliance (GCPA). The Mission aims to work with international partners to identify and deliver crucial changes needed to diversify clean power supply chains and address bottlenecks. It was formally launched at the IEA Future of Energy Security Summit in April

2025, where a Ministerial roundtable hosted by the Secretary of State for Foreign and Commonwealth Affairs and the Secretary of State for Energy Security and Net Zero of the United Kingdom highlighted the critical importance of collaboration to strengthen global clean energy supply chains – including with regards to data – garnering broad support from international partners.

The Supply Chains Mission is organised around four pillars, focusing on: 1) Data; 2) Electricity Transmission Systems; 3) Circularity; and 4) Supporting emerging markets and developing economies (EMDEs). The Data pillar involves identifying challenges and proposing recommendations to improve the accuracy, granularity, and overall quality of supply chain data on clean energy technologies, such as on production capacity, output, demand, trade and investments. Improving the availability of and access to the data is also one of the goals of this pillar. The Mission's specific focus on EMDEs is motivated by the fact that large parts of supply chains are located in EMDEs. At the same time, these countries face the biggest challenges in collecting and disseminating relevant data.

Improved supply chain data is essential to inform evidence-based policy making on clean energy technology manufacturing in different countries, as well as reflections on strategic trade partnerships, both of which can contribute to enhancing energy security. EMDEs could benefit the most proportionally, as better data could support strategic expansion of their footprint in clean energy supply chains, contributing to increased industrialisation of these economies. As set out above, securing clean energy supply chains can also contribute to economic development and to alleviating wider security concerns.

However, given the globalised nature of manufacturing and trade – and the competition inherent in international markets – achieving transparent and comprehensive supply chain data collection is very difficult. Companies positioning themselves in supply chains face strong competition and are unwilling to report or share their data that could reveal commercially sensitive information. For countries aiming to encourage a new clean energy manufacturing sector, gaining access to the data from these companies and their competitors can help with tracking development. There is therefore a need to balance concerns around commercial sensitivity with the need for transparency at the country level in support of various policy goals, including energy security and industrial development.

In the absence of data collections undertaken by national authorities, private sector data providers can often provide paid services to fill the gaps. Such data is often used in lieu of official statistics, despite it not necessarily satisfying the rigorous methodological requirements of official statistics and often lacking comprehensive coverage.

The existing data landscape

High-quality, timely data is necessary to answer many different questions relevant to policy making on energy technology supply chains, such as:

- Which countries have undeveloped mineral resources that could be mined competitively to satisfy future demand and diversify supply?
- What kind of manufacturing could be developed competitively in a particular country to position it in a given clean energy supply chain?
- What is a given country or industry's exposure to a particular trade partner for a given technology (which may have implications in the case of embargoes, sanctions, or disruption caused by a geopolitical event or natural hazard)?
- What is the vulnerability of a particular trading route to natural extreme events, conflict, piracy and other possible events? How does this impact energy security?
- What is a given industry's exposure to price increases for particular materials/components?
- Where are the opportunities to increase trade with and investment in EMDEs, and refining, assembly and manufacturing capability in those economies, in order to expand the global supply of minerals, components and technologies?

The current state of data on clean energy technology supply chains is, in many instances, insufficiently robust for answering these types of questions that governments may face. After confirming the scope of the assessment in this report, this section explores the *status quo* – and the various associated challenges – of the existing data landscape.

Scope of this report

There is no generally agreed list of materials and products that can be categorised as being part of "clean energy supply chains" or "net zero energy supply chains". The lists used by different institutions therefore differ, sometimes quite significantly. Typically, Harmonized System (HS) codes are used to describe the sectors and goods covered in different analyses (see Box 2). The Climate Change Indicators Dashboard of the International Monetary Fund uses up to 124 different HS codes (using the 2017 version of the HS) for their definition of low-carbon technology products. The World Bank uses 107 HS codes to define low-carbon technologies in their analysis. The manufacturing and trade components of the IEA's Energy Technology Perspectives (ETP) publications have tended to focus on six key clean energy technologies: solar PV, wind, EVs and batteries, heat pumps and electrolysers, as well as these technologies' main components. Research underlying ETP analysis on clean energy technology supply chains therefore uses 22 HS codes overall, some at 6-digit and others at 8-digit level, depending on data availability. The documentation for the IEA's Manufacturing and Trade (MaT) model – both the technical annex to ETP-2024 and the forthcoming standalone edition of the documentation – provides further information on the HS codes used in ETP analysis.

While HS codes are generally recognised across the globe and used in many countries, which provides some consistency in the data related to clean energy technology supply chains, there can be drawbacks, as the codes are not always sufficiently detailed or cover multiple products or components. For example, code HS811299 contains multiple REEs. There are no specific codes for high-voltage direct current (HVDC) cables or certain components related to emerging sectors such as low-emissions hydrogen. Due to the long lead time for introducing new codes into the HS, a specific code for solar PV panels was introduced only in 2022, even though the global market for solar PV had been growing exponentially for over a decade. This delay in the creation of new codes remains an obstacle to keeping track of new technologies that are often growing exponentially.

The European Union uses detailed 8-digit codes, developed under the Combined Nomenclature (CN), as well as Prodcom codes, which have some correspondence to HS codes. For tracking of the EU Net-Zero Industry Act (NZIA), the implementing regulation identified 55 CN [3] codes to track (see Communication C/2025/3236 from the Commission, Table 3), which specify "net zero technology" final products and their main specific components. For the technologies not currently covered by this list, there is a lack of detailed statistics, and the European Commission is in the process of developing the additional CN codes specific to these technologies in order to be able to track them. Similarly, an ongoing workstream at the OECD Trade Committee tracks how national trade nomenclatures in different economies are being adapted at 8, 9 or 10-digit levels for more accurate measurement of critical raw materials and the related technologies in trade statistics, with a recent focus on cobalt, lithium and nickel.

The Energy Technology Perspectives series – the analytical foundation for this work – has tended to focus on the supply chains for six mass-manufactured technologies: solar PV, wind, EVs and batteries, heat pumps and electrolysers. In the context of this report, 'clean energy technology supply chains' is inclusive of these technology supply chains, but also more broadly to the technologies, components and materials that underpin the Age of Electricity, including grid technologies and critical minerals.

[3] CN codes and their product descriptions refer to the CN 2025 classification.

Box 2. The Harmonized System

The Harmonized System (HS) is an international classification system standardised between countries at a basic 6-digit level[4], with country-specific definitions for the 8- and 10-digit levels. It is used to classify physical goods, with the aim of facilitating international trade and the collection and analysis of statistics by harmonising descriptions, classification and coding of internationally traded goods. Such harmonisation reduces expenses related to international trade and facilitates the standardisation of trade documentation and transmission of trade data. The HS is used for the collection of customs and trade statistics, as well as the application of tariffs and collection of internal taxes in some countries, and serves as a basis for certain trade negotiations. It is now used in 212 countries to classify over 98% of the world's trade.

However, certain factors can reduce the reliability of statistical data based on the HS. These include use of older editions of the HS, which reduces comparability between countries; incorrect classification of goods, or variable classification practices of different countries, which results in differences between exporting and importing countries. Differences in recording quantities of goods (there is no requirement to record this, but it is recommended) also result from countries using different practices for recording (e.g. weight, number of units, etc.).

When focusing on clean energy technologies, it is important to note that HS cannot capture all the attributes of goods that are important for policy makers. Goods are classified under HS codes based on the physical attributes of goods verifiable at the border. This therefore cannot cover aspects such as their pre-border origin (e.g. if they were produced with low-emissions energy) or their post-border final use (e.g. if they will be used for a particular sector relevant to clean energy, if they also have other uses).

The HS is subject to a continually rotating review cycle, with each cycle resulting in a new edition of the HS every 5 years. The latest version of the HS was approved in June 2019 and entered into force on 1 January 2022. The next version will enter into force on 1 January 2028 (the 6-year cycle for HS2028 was set up to account for the impact of the pandemic) and submissions of proposals for new amendments to the 2033 edition of the HS are currently open.

[4] The HS, like other classification systems, uses code numbers to define products. A code with a low number of digits defines broad categories of products; additional digits indicate sub-divisions into more detailed definitions. Six-digit codes are the most detailed definitions in HS.

Data categories

Many categories of data are needed in order to build a comprehensive picture of clean energy technology supply chains, and to track their evolution.

The main data categories of interest are:

- mineral reserves data (geological surveys; by region/country)
- production levels (for minerals, components, final products; by producer/country, by month/year)
- production capacities (for minerals, components, final products; by producer/country, by month/year)
- trade data (for minerals, components, final products; by country, by month/year; by volume and by monetary value)
- prices (for minerals, components, final products; by producer/country, by month/year)
- investment data (by type of processing/manufacturing facility; by producer/country, by year)

Additional types of data helpful for overall assessment are:

- demand forecasts (for minerals, components, final products; by country, by year)
- production costs (for minerals, components, final products; by producer/country, by month/year)
- number of jobs and types of skills needed for all stages of the supply chains and the related labour costs (per type of job; by country, by year)
- energy technology RD&D data (patents, budgets, etc)
- trading routes (maritime, terrestrial)
- trade policy measures like tariffs, duties and export restrictions.

For example, combining data on investments with demand forecasts allows governments to assess possible future shortfalls in supply, by checking if investment data indicates adequate coverage of the expected demand. Labour needs also have to be assessed ahead of any supply chain expansion, as a shortage of skilled labour in any part of the supply chain can represent an important bottleneck, especially since training skilled labour often takes multiple years.

The types of data can also be classified by the methods used to source them, which have a direct impact on their quality:

- **Standard annual data collected by national statistical offices (NSOs), typically based on primary data collections.** These include surveys or direct reporting to NSO as mandated by law. This data is generally very comprehensive and compiled by national agencies following international standards. Production of such data takes multiple months and up to a year, after the end of the reporting year. International organisations can also collect this data, for example through questionnaires, and use them directly. For example: wind power installed capacity per country per year.

- **Standard monthly or quarterly data collected by NSOs**. This data is generally less comprehensive than annual data, and definitions and methodologies do not necessarily follow international standards. Production of such data takes between a few weeks and a few months; international organisations sometimes need to bring the data to international standards to achieve comparability. For example: wind power generation per country per month.
- **Ad-hoc data collected by NSOs or modelled**, **if collection is not possible.** These data are often produced in a time-limited manner (e.g. a specific survey for a particular project, or a modelling-based estimation before a more robust data collection is established) and typically follow national definitions and methodologies. It can be difficult for international organisations to bring such data to international standards to achieve comparability. For example: electricity used for charging of EVs per country per year, based on a combination of data collected from commercial charging stations, combined with modelling of consumption of charging stations in the residential sector.
- **Data compiled regularly or occasionally by governmental agencies other than NSOs.** The datasets created may be based on administrative data, for example, which can imply that definitions and methods do not necessarily follow the requirements for national or international statistical data collections. For example: installed capacity of heat pumps in the residential sector per country per year; statistics could be produced using administrative data on subsidies for heat pumps, if subsidies are available to all residential consumers.
- **Data compiled by international organisations, industrial associations, commercial or other entities based on voluntary surveys or similar methods of primary data collection.** Data are often produced in an irregular manner and rarely achieve representativeness of their samples; definitions and methods do not necessarily follow national or international requirements for statistical data collections. For example: The IEA's Cost of Capital Observatory.
- **Data compiled by international organisations, industrial associations or commercial or other entities based on desk research, web scraping and other non-structured data collection methods.** Data can be produced regularly or occasionally; it is hard to achieve comprehensive coverage since the data collection relies on data available in an irregular manner. Definitions and methods are not standardised and do not follow national or international requirements for statistical data collections. For example: Investment costs of projects as provided by commercial data providers – these are typically collected based on press releases, companies' annual reports and reports of development banks, etc.

Data sources

There is currently no authoritative "one-stop-shop" source for clean energy technology supply chain data globally. This is partly due to the complexity of supply chains, which often cross borders and span many different industries, some of which are relatively immature, and partly because there is no dedicated international organisation with the mandate to collect comprehensive, granular and standardised data on supply chains.

As a result of the keen interest in clean energy technology supply chains and importance of assessing their implications for energy security, analysts typically use different sources of available data to compose a partial picture of supply chains of interest, with various degrees of success.

The data sources used to trace different parts of clean energy supply chains come from the following types of data sources and databases:

- Data provided by geological surveys, such as the British Geological Survey or the United States Geological Survey.
- IEA annual data collections (for example on the installed capacities of certain clean energy technologies, based on annual electricity and renewables questionnaires for selected countries, information on production of certain commodities, diffusion of heat pumps and EVs in energy end-uses and efficiency indicators, based on a questionnaire for selected countries).
- Trade statistics, including customs data from individual countries, as well as international sources, such as the UN Commodity Trade Statistics Database (Comtrade), Eurostat Comext, Trade in Critical Minerals database of the World Trade Organization (WTO) and the BACI dataset of the CEPII research centre.
- Input-output tables, describing relationships between producers and consumers within economies, in individual countries but also at the international level (e.g. OECD datasets).
- Clean energy technology-specific industry association data, for example covering capacities/production of relevant parts of supply chains (e.g. Global Wind Energy Council data).
- Work of academic institutions covering supply chains (e.g. The Joint Research Centre's work on wind supply chains).
- Commercial databases providing wide-ranging market intelligence on clean energy technologies, including investments, plant-specific information, prices for traded commodities, etc (e.g. BNEF, S&P).
- Geospatial databases, tracking (among others) industrial facilities (e.g. the CORDA database by Copernicus, covering EU member states).

The diversity of available data sources listed above brings a wealth of information, but it is not without challenges, in particular related to various aspects of data quality and comparability, which are further discussed in the next section of this report.

In addition, for the above-mentioned data sources to be useful for analytical and modelling purposes, they often need to be complemented with additional information, such as:

- prices of different minerals, metals, materials and components
- energy prices (e.g. the IEA energy prices database)
- labour costs
- energy technology RD&D budgets (e.g. the IEA Energy Technology RD&D Budgets database)
- energy and material intensities of different processes
- detailed and up-to-date mapping of clean energy technology supply chains
- information on export controls and restrictions (e.g. OECD annual updates on export restrictions on industrial raw materials).

These data are not always easy to obtain. For example, price data on minerals that are not openly traded are not easily available, leading to reliance on commercial providers. It is also difficult to track market responses to key economic events such as trade restrictions in the absence of open trade. There is also a knowledge gap on precisely how much raw material is used in the final outputs of clean technology supply chains, even though understanding the links between the costs of raw materials and the costs of final equipment is crucial for policy making. As noted above, the composition of these technologies also constantly changes with innovation progress. Labour costs are also not easy to ascertain, in particular for EMDEs, where large parts of supply chains are situated, and where a part of labour is informal.

The existing data landscape differs considerably between countries. As part of the monitoring obligations stemming from the EU Net-Zero Industry Act (NZIA), EU member countries will be obliged – as of 2027 and at least every 3 years thereafter – to collect various categories of supply chain data, such as manufacturing capacity, for certain "net zero energy technologies", as designated by the European Commission. By contrast, little data is available for EMDEs. Some countries may also lack incentives to be fully transparent about their supply chains, either to maintain competitive advantage or to avoid close scrutiny of activities.

The most comprehensive and consistent data is available for EU member states, due to the requirements of the European Commission for regular reporting, and standardised procedures at the country level that ensure consistency and comparability of data within Eurostat datasets. Additionally, once published, Eurostat data are free of charge, contributing to the transparency of information. With compulsory reporting for the NZIA beginning in 2027, more information will become available on the manufacturing capacity for the "net zero energy technologies" the European Commission designates, as well as on the value and volume of trade of such technologies.

A lack of data may also result in a reliance on commercial databases and subscription services that often offer only anecdotal evidence of investment costs, or other types of project-level data. Many different subscriptions are needed to achieve a comprehensive picture of clean energy supply chains, which comes at a cost. The costs of commercial databases are borne by governments to facilitate their own analyses, as well as the work of international organisations. These costs represent a significant and recurring financial burden carried by the governmental budgets of high-income countries. Lower-income countries typically do not have full access to commercial databases, due to their prohibitive costs, leaving them at a significant disadvantage for determining their positioning in clean energy technology supply chains.

Data quality

Clean energy technology supply chain data – as currently available and used for analyses – lack adequate quality across multiple dimensions. Best practice guidelines for OECD statistical activities suggest that the following aspects of data need to be tracked to assure data quality:

- relevance (statistics meet the needs of users)
- accuracy (statistics accurately and reliably portray reality)
- credibility (users place confidence in statistical products)
- timeliness (statistics are released in a timely and punctual manner)
- accessibility (data can be readily located)
- interpretability (ease with which the user may understand and properly use the data)
- coherence and comparability (statistics are consistent internally, over time and in space, and it is possible to combine and make joint use of related data from different sources)
- cost-efficiency (measure of the costs and provider burden relative to the output, which may affect all the above-mentioned dimensions of quality).

These aspects are explained in detail below. It is important to point out that depending on the type of analysis undertaken, data of differing quality can be acceptable for analyses without jeopardising their results. There is therefore no simple judgement on what constitutes "good-quality data", and any judgement should instead be based on the notion of "good-enough quality data for achieving a particular goal".

Relevance

The clean energy technology supply chain data currently available do not fully meet the criteria of relevance, since user needs are clearly not fully met by current data availability, whether in the public domain or from commercial entities. There is a lack of granular data on production capacities and production outputs of most parts of supply chains, with country coverage varying widely and poorer data coverage from EMDEs than from OECD countries. Investment data are almost entirely missing, with some data available from commercial providers, but these are often initial estimates of deals, rather than actual ex-post reported data. This lack of information limits modelling with country-level detail, for example. Importantly, it limits the ability of countries to identify with adequate precision future opportunities for the expansion of supply chains, or risks to their current supply chains. Lack of detail in current descriptions of the composition of supply chains hampers the traceability of raw materials and specialised components through supply chains. This could potentially exacerbate supply risks, which may in turn result in energy security risks.

Accuracy

The lack of statistical data described above also impacts accuracy. By definition, use of estimates does not reliably portray reality. Poor coverage also contributes to the lack of accuracy. For data that are statistically measured, such as trade data tracked at border crossings, differences can be observed between reports from exporters and importers. These can be caused by inconsistent use of HS codes among countries (e.g. exporting countries may pay less attention to proper classification than importers, which may need to apply appropriate tariffs or duties based on detailed classification), misclassification of goods on one side of the border, or genuine disagreements between countries on how to classify certain goods.

With the exception of trade data, other data used to assess clean energy supply chains are mostly collected from various industry reports, or estimated based on news reports on industrial facilities. These are not typically collected following any agreed statistical methodologies and do not comply with commonly agreed definitions, which makes comparison across such data difficult. The data are therefore not representative of the whole range of entities they attempt to track. Moreover, industry sources often do not indicate the precise source(s) of their data, so the user often is unable to ascertain if the datapoint is an in-house estimate by the data provider or has been reported by the industry or industrial facility in question, albeit not using any well-established methodology. The provision of metadata [5] for all data resources would help to improve data transparency, even if it would not resolve issues with accuracy.

Credibility

Given the overall patchiness of the data related to clean energy technology supply chains, users typically have low confidence in the data. As noted above, trade data is quite credible as it is well-defined and collected systematically, even if isolated issues may arise. However, the rest of the clean energy technology supply chain data lacks consistent coverage and is not transparent on methods of data collection or estimation, undermining its credibility. This lack of credibility is precisely why the Data pillar of the Supply Chains Mission under the Global Clean Power Alliance targets improving data availability and quality for clean power supply chains.

Timeliness

The timeliness of data is often inversely related to its accuracy. A datapoint from a news clipping may be very timely, but if it does not satisfy agreed definitions and methods of collection, such a datapoint often cannot be meaningfully compared with other datapoints, creating an inconsistent dataset. In addition, the regularity of such a method of data collection is not guaranteed. There is no fixed schedule, and users therefore cannot rely on regular releases available for their use, nor on time series availability, undermining the usefulness of such data, particularly for periodic assessments.

Collecting accurate statistics such as trade data takes more time, as the collected data needs to be brought in line with common standards, verified and otherwise consolidated. Statistical data collection also comes with a defined data release schedule, enabling users to plan for data availability. Statistical data at a country level is typically available with a lag of a few months for monthly data, and up to a year for yearly data (annual consolidation typically takes longer in larger countries). Consolidation at the global level takes additional time as it depends on having data available from most countries in order to achieve comprehensive coverage.

The biggest issue related to the timeliness of clean energy supply data is related to the processes of issuing of new codes, whether HS codes, CN codes or others. Processes for new codes are lengthy, often requiring years from the proposal of new codes through to approvals and eventual adoption. In the context of rapid innovation in clean energy technologies and their components, the processes for

[5] Metadata is information describing the characteristics of data, such as author/owner, date of creation, method of collection, etc.

new codes are ill-suited to keep pace with technology development. Additionally, certain elements of supply chains may represent very small amounts of trade, and therefore do not warrant separate codes from a trade volume or value point of view, yet may be irreplaceable in supply chains – and therefore crucial for energy security – but end up being hard to track based on codes. Making the case for the inclusion of codes for these critical elements is an important part of possible improvements to clean energy supply chain data.

Accessibility

The accessibility of certain data on clean energy technology supply chains is hindered by confidentiality. Given that some parts of these supply chains are new, there are only a few players involved, and revealing their information could put them at a competitive disadvantage. For nascent industries, statistical information often needs to be kept confidential until the number of actors is sufficient to ensure that they cannot be identified in aggregate information. This is a general rule in most official statistics, and such confidentiality issues are resolved over time as the given segment of the industry grows and diversifies.

Accessibility issues may also arise when countries lack of willingness or incentives to be transparent about their supply chains, either in order to maintain competitive advantage or to avoid scrutiny of potential environmental or social issues related to mining, processing and manufacturing activities. However, they can also result from a lack of resources for recurrent data collections and dissemination of findings, particularly in EMDEs.

A bigger and persistent issue relates to access to commercial data services, which in the absence of governmental data are the primary source of data on clean energy supply chains. The licenses for these services can be costly, and structured in ways that can restrict sharing of data between colleagues and across different departments of the same institution, undermining co-ordination and creating information asymmetries. The only way to avoid these drawbacks is through separate purchases of multiple licences, which can make data acquisition prohibitively costly. Commercial services can also perpetuate the advantages of larger and more affluent countries or companies that can afford access, which potentially gives them a competitive advantage, adding to their dominance and preventing other countries or companies from entering the market.

Interpretability

Commercial data services and industry data rarely provide metadata, making it hard to understand the origins of the data. Data that have been collected may be treated and reported by these services in the same way as rough estimates based on desktop research, without communicating the information on these different origins to the data users. This undermines the ability of users to properly use the data. For example, users may end up treating these two types of data as if they were of the same quality, potentially weakening the value of their analytical work or modelling based on such data.

Coherence and comparability

To achieve high quality, data need to be consistent internally and comparable over time and across sectors or geographical units. This is not always the case of clean energy supply chain data. Trade data can suffer from inconsistency between countries of origin and destination, as well as issues with misreporting. Changes of HS codes over time cause a lack of full comparability over the time series, even though additional more detailed codes do bring more information with each new version of the HS. Varied templates for industry reporting and a lack of metadata for industry and commercial data sources can also hinder comparability in time, across sectors and across geographies. This is, for example, the case of differing templates for reporting critical mineral reserves, such as the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) and the United Nations Framework Classification (UNFC) for Fossil Energy and Mineral Reserves and Resources. Initiatives such as the CRIRSCO-UNFC Bridging Document help to bring comparability to different reporting systems and highlight the need for coherence in classifications and coding systems. Unlike CRIRSCO, the UNFC also recognises critical minerals that are sourced as by-products and are therefore at risk of under-reporting in capital markets focused on investor priorities.

Cost-efficiency

The cost-efficiency of the current set of data available for clean energy supply chains is relatively low. A lot of data is behind different paywalls, and the structure of licences to access this data is such that even within the same government agency or company, there may be a need for dozens of licences to gain access. Moreover, while some commercial and industry data have regular releases, others may provide information that is timely at the moment of publication but appears according to a relatively arbitrary schedule. This complicates its use for systematic analyses that can inform regular assessments of the market situation or the evolution of competitiveness over time. When overall costs are summed up at a country level, they easily reach hundreds of thousands of US dollars, or more, making reliance on commercial data very costly.

Boundary issues

Many materials, components and even some types of equipment that form part of clean energy technology supply chains are not exclusive to those supply chains.

This makes tracking of the supply chains even more complex, because of competition with other industries.

Establishing tracking of these materials, components and equipment implies defining boundaries of what to track and what lies beyond the scope of tracking, but materials, components and equipment used by multiple industries blur this boundary. For example, while it is important to track the polysilicon used for solar PV panels, the polysilicon used in mobile phones is not relevant to clean energy technology supply chains. Some common materials that are part of clean energy technology supply chains are also parts of many other supply chains, such as steel and cement, which are heavily used in construction, or copper, which is needed for all electrical equipment, not just clean energy technologies. Many other such examples exist.

The difficulty of tracking these materials arises because it is not necessarily clear at the point of production what the final use of the material will be – and therefore if it is actually of interest for the statistical data collection being undertaken. There are parallels in energy statistics: Fossil fuels are tracked for both their energy uses and non-energy uses, such as in the petrochemical industry for the production of plastics. However, energy uses are dominant, so tracking non-energy uses is a relatively smaller task that completes the picture. In the examples from the clean energy technology supply chains noted above, these supply chains are far from being the main destination of the materials to be tracked, meaning that a different approach is advisable in order to make the best use of time and resources.

In practical terms, when identifying classification codes, whether HS, CN or others, in order to start tracking, it is important to define if the given code covers only products that are part of clean energy technology supply chains (e.g. a code for solar PV panels), or if the code partially covers a part of a clean energy technology supply chain and partially covers other industries (e.g. a code for copper). For codes that cover elements of both clean energy supply chains and other supply chains, further analysis is needed to disentangle the two categories. For example, it may be useful to use more detailed, country-specific codes, but the approach may need to differ from one code to another, which makes this a potentially very complex and laborious task.

Use of existing data

In order to build a coherent, comprehensive picture of clean energy technology supply chains, the aim should be to broadly cover all stages of the different supply chains concerned, across all relevant metrics, such as production, trade, prices, investments, and so on. However, data is not currently available on all relevant areas, especially not with sufficient geographic coverage. Some technologies, such as solar PV, have far better coverage than others; for heat pumps, for example, the market is far more fragmented, with a lot of national production, trade that is regional rather than global, and difficulties in tracking certain regions, in particular those containing EMDEs.

Different sources are published with different frequency and sometimes unpredictable and irregular timing, particularly by commercial providers, which complicates regular updates to datasets. The variety of sources and diversity of methods used for these data collections pose additional challenges. To create a coherent dataset, where possible, data needs to be processed to comply with common definitions, converted to comparable units, separated in a consistent way into geographic units, and updated based on a regular schedule. If full alignment of definitions is not possible across datasets, this should be clearly highlighted to data users, so that they can take it into account in their analyses of the data.

Gaps in the datasets, such as missing values for certain years, or a division from a regional aggregate to country-specific data, need to be filled with estimates, which need to be produced using methodologies that are coherent within the dataset and clearly described in accompanying documentation. This represents a significant amount of data processing, harmonisation and estimation. Furthermore, this is often hampered by imprecise conversions (e.g. between volume and energy, when precise calorific values are not known, or between volumes and monetary values), and the lack of metadata describing the various original data sources. For example, in the absence of metadata, it is not possible to know if a zero in a dataset means the value of the variable is indeed zero, or if the value was not reported, or is missing. Similarly, it is impossible to know if a given value is an observation or an estimate. Additional difficulties may arise from formats in which data sources are published. Some commercial providers distribute data exclusively as PDF files in which the underlying data is embedded in charts, rather than providing data in machine-readable formats such as CSV or Excel files.

During data processing, all data manipulation should ideally be recorded in a log or manual, including all the assumptions, proxy variables used, and so on. Such a log can help users to recreate all the steps in the future, or to re-process the dataset in case a proxy needs to be changed (because a better proxy has become available), or other methodological changes are needed. For example, when an additional year is to be added into the dataset, a log helps to add it in a manner fully coherent with the previous years. All metadata reflecting original sources, as well as the processing undertaken, should be saved as an integral part of the dataset.

Policy considerations

Policy makers are paying increasing attention to the evolution of clean energy technology supply chains, but – as identified in this report – at present, the availability, completeness and quality of data on those supply chains are not always sufficient to underpin evidence-based policy making. Governments can take many potential actions to help to enhance the data landscape. While there are actions they can take individually, some of the challenges will be less tractable without a co-ordinated approach. Capitalising on the recent increase in political attention paid to clean energy technology supply chains in many countries, the Data pillar of the Supply Chains Mission of the GCPA is well-suited to leverage the political will needed to achieve this co-ordination, particularly if it engages with existing relevant national and international initiatives.

In this section, we start by suggesting an initial scope of specific data categories to focus on, and then identify a non-exhaustive series of potential government actions that could be undertaken to improve the existing data landscape. We conclude with a suggested prioritisation of potential actions as an input to the discussions taking place among those engaging in the Supply Chains Mission.

Data frameworks

A pre-requisite to determining an appropriate set of government actions to improve the current state of supply chain data is to decide which categories of data need to be collected and tracked, at what frequency, in what units (e.g. monetary, mass, rated power output) and at what level of granularity – i.e. the scope and dimensions of a supply chain data framework.

As covered in the sections above, data collection processes face many challenges, which can be expensive and time-consuming to overcome. The investment in data collection required is small when compared to the benefits of the commercial investment and industrialisation it could enable, and of resulting improvements in energy security, but the scope of the data to be collected should be sized according to a country's needs, and specifically to the questions the data can help to answer. Examples of such questions and the associated key categories of data – including both supply chain data and other relevant datasets – that they might necessitate collecting are as follows:

- What is a given country or industry's exposure to single country for a given technology? *Key data required: production and capacity data for all countries; trade data; prices and production costs, particularly for domestic downstream customer industries to estimate the economic consequences of a disruption.*

- Which countries should be approached to form strategic partnerships at a given step in a supply chain? *Key data required: existing and announced capacity; production costs; trade data; prices.*
- What are the most competitive firms in a given supply chain that should be attracted to make investments and form joint ventures with domestic firms? *Key data required: Firm-level financial, production and capacity information; estimated investment requirements and production costs; estimated employment associated with a given facility.*
- At what point in a given supply chain the government deems as a strategic industrial sector should it seek to build domestic capacity? *Key data required: estimated domestic production costs and those of peer competitors; price, trade volume, production and capacity data for inputs and outputs at each supply chain step.*
- Should a given domestic mineral resource be developed vs. buying the resulting commodity on international markets? *Key data required: mineral reserves; estimated upfront and operational cost for operating a new domestic mine and associated refining facility; production, capacity and potential off-take quantities of downstream customer industries; international market prices, both long-term contract and spot prices where relevant.*

Different countries will have different priorities and therefore different questions to answer, but there will be many common data ingredients to their industrial strategy recipes. While establishing these commonalities among governments' data needs will be one of the cross-cutting elements of the Supply Chains Mission, an initial suggestion of the scope of a common tracking framework is provided as an input to these discussions in Table 1.

While more data is usually better than less, the categories, frequencies and units of data outlined in Table 1 would constitute a good starting point for answering the types of questions many governments face when designing their industrial strategies. This selection, and the stipulation of different frequencies and units for each data category, are somewhat subjective, but are based on experience gained in the Energy Technology Policy Division of the IEA, during the publication and dissemination of ETP-2023 and ETP-2024.

Table 1 Suggested scope of a common energy technology supply chain data tracking framework

Data category	Energy technology supply chain step					
	Minerals	Materials	Components	Equipment	Deployment	Recycling
Reserves	Physical units, annual frequency					*Estimated physical units, annual frequency
Production	Physical units, annual frequency				*Data on clean energy technology deployment, such as EV sales, solar PV installations, electricity trade and prices are already collected and made available by the IEA in other workstreams and datasets*	Physical units, annual frequency
Existing & announced capacity	Physical units, quarterly frequency					Physical units, annual frequency
Trade	Physical and monetary units, monthly frequency					Physical and monetary units, monthly frequency
Prices	Monetary units, up to daily frequency					Monetary units, up to daily frequency
Production costs	Estimated monetary units, annual frequency					Monetary units, annual frequency

Relevant to track (light grey) | Not applicable (dark grey)

* Data on reserves associated with the recycling step in supply chains corresponds to stocks of goods and scrap material that could form an input to future production.

Domestic actions

Domestic actions governments could consider in order to improve the existing data landscape for clean energy technology supply chains are as follows:

- Ensure that the regulatory framework supporting clean energy supply chain data collection is fit for purpose to achieve the desired data coverage. This framework should set clear requirements on what the data collection obligations are and which entities are responsible for ensuring that they are fully met. This may require new – or modifications to existing – legislation and associated funding.
- Observe legal provisions governing statistical confidentiality. These provisions often do not allow statistical units to be identified directly or indirectly, so as not to disclose sensitive information pertaining to individual entities, and are therefore particularly important when there are few actors operating in a given supply chain. As the number of entities involved increases, these provisions can form less of a constraint and more data can be published.

- Designate an entity with overall responsibility for co-ordination of clean energy supply chain data collection efforts, and for clearly dividing tasks among relevant agencies, in order to avoid duplication of efforts and to minimise data gaps.
- Invest in up-to-date mapping for strategically important domestic supply chains and co-ordinate with other countries, where feasible, to share the results and avoid duplication of efforts.
- Define clear mechanisms for fostering data exchanges between different entities in line with the existing statistical practices, such as data-sharing agreements, Memoranda of Understanding, or the creation of working groups designed for clean energy technology supply chain data exchanges. The responsible authorities should be sufficiently empowered so that data exchanges between different entities in the country are as efficient as possible.
- Mandate compulsory high-level data reporting for all new mining concessions and new production facilities of strategic importance as an integral part of governmental approval processes. Such data collection, if needed, can be done under confidentiality agreements with government so that strategic decisions can be taken without revealing individual company data. This can be an important avenue for sharing the costs of data collection between the public and private sectors, particularly in EMDEs.
- Explore the use of existing administrative data to supplement existing statistical data collection undertaken through censuses and surveys and decrease costs of data collection processes (see Box 3).
- Conduct cost-benefit analyses of subscription services for proprietary data services and data collection processes undertaken by external contractors. Such analysis should also take into account potential data confidentiality considerations and the possibilities for governments to obtain data from industry under confidentiality agreements. These data can then be used to inform internal government decision-making, without making the data public.
- Based on the cost-benefit analysis, deciding on the data collection processes that need to be done 'in-house' by a government entity, those that can be done by industry, and those for which commercial arrangements with external contractors are sufficient. Wherever possible, the positive spillovers of making these datasets publicly available should be considered in the cost-benefit analyses and decisions around performing the data collection 'in-house' vs. relying on an external provider.
- Pursue an all-of-government approach to procuring contracts for external data providers, where this is deemed the best approach. Aggregating the various users of subscription services across a given provider's various services can often yield lower overall costs.
- For data collection processes administrated 'in-house', allocate sufficient budget and staffing across the relevant institutions and departments, together with the necessary operational expenditure on information technology and staff training to maintain best practices and continual efficiency gains. This is an area where

capacity building and support to EMDEs could be of merit. For further information on how to set up national country-level data collection, see the IEA's Designing an Energy Statistics Roadmap. While this publication focuses on energy statistics, many of its insights are transferable to setting up other statistical data collection processes.

- Establish appropriate data dissemination channels (distinguishing between data that can be made public and data that is available to a restricted group of stakeholders, whether internal or external) and including sufficient metadata to ensure transparency. Feedback sought from users of the data can ensure that the processes remains relevant and fit for purpose.
- Regularly evaluate and modify processes if further additions are needed, for instance to reflect technological advances, or to remove datasets that are obsolete.

Box 3. Use of existing administrative data for clean energy technology supply chain data collection

A wide range of governmental agencies and industry associations may collect data in response to legislation or regulations, typically to assess the outcomes of government policies or programmes. Data collection processes of this kind usually result in a register of the entities bound by the given regulation/legislation and the data resulting from application of the regulation/legislation. This register and the related data are referred to collectively as administrative data. Such data can be very useful for compiling high-quality statistics.

For example, for any type of government support or subsidies to R&D or deployment of clean energy, a government agency compiles a register of entities that received support. Similarly, any activity that requires a government permit is listed by a permitting registry. Collecting data through these administrative processes can be a low-cost way to obtain relevant information on aspects of clean energy technology supply chains. Administrative data has been used in the past, for example to develop statistics on the deployment of distributed solar PV and of heat pumps, in particular in EU member states where these technologies have received diverse forms of governmental support.

Use of administrative data reduces the overall cost of data collection and reduces the burden for respondents. It can also result in fewer, less series errors than using surveys, can be sustained due to minimal additional cost and long-term accessibility, and can mean there are regular updates, among other advantages. This can be very beneficial, particularly where there is a lack of funding for data collection processes, such as in many EMDEs.

Possible limitations in the use of administrative data include inconsistencies in the concepts and definitions used (though this can be avoided if statistical use of the data is planned from the start and relevant definitions are applied), lack of quality assurance of the administrative data; and possible legal constraints with respect to access and confidentiality. When data comes from industry associations, governmental statistical agencies must ensure the quality and objectivity of data being provided by such associations, for whom data collection is not a primary activity.

Actions requiring international co-operation

In theory, once domestic datasets are established, they can be aggregated to provide a global picture – or a partial version thereof. In reality, much needs to be done to ensure harmonisation and interoperability between national datasets. There is also much to be gained from countries' interactions with each other, with regards to avoiding duplication and sharing best practice. Actions that require some degree of international co-operation that governments could consider in order to improve the existing data landscape for clean energy technology supply chains are as follows:

- Clearly assign data collection responsibilities among existing international institutions (and/or new entities, if necessary) and provide a common sense of the mission associated with the data collection activity. Appropriate resources should be mobilised to support these data collection efforts; temporary secondments of staff from national statistical institutions to international institutions can help to promote harmonisation of statistical practices among countries, and build capacity.
- Collaborate with other countries to establish common statistical definitions, classifications and data collection methodologies for clean energy technology supply chain data. Engagement in international standard development can help structure the development of these methodologies and processes in a way that helps maximise interoperability between countries and datasets. This process needs to be iterative, adjusting processes and classifications to account for the latest technological developments.
- Actively engage with institutions that govern the classification systems around trade data, most notably the World Customs Organization (WCO) and its maintenance of the HS (see Box 4). Other international bodies besides the WCO are also relevant when it comes to trade data for clean energy technology supply chains; OECD Trade Committee compares how selected critical raw materials and technologies map onto the national trade nomenclatures of several countries, with

the objective of identifying best practices. Engagement can help make sure that these classification systems remain fit for purpose in the Age of Electricity.

- Capitalise on existing regionally co-ordinated data collection processes where relevant, to benefit from acquired experience and avoid duplication of efforts. An example of this could be through the establishment of joint questionnaires, as is done for energy statistics through the joint annual questionnaires of the IEA and Eurostat.
- Delineate transparent methods of data estimation to guide countries' efforts to populate elements of missing data in such a way that is replicable by users, and codify these methods in documentation. For these purposes, statisticians producing international statistics benefit from exchanges with modellers and analysts – such interactions should be facilitated within, or between, the relevant institution(s) tasked with collecting the data and producing the statistics.
- Promote knowledge transfer and sharing of best practices among countries to ensure the highest possible quality of national and global statistics. An example of this could be sharing best practices during the process of revising national trade nomenclatures for mapping mineral flows in trade statistics. This is an area where advanced economies could help with capacity building (training, knowledge transfer, software etc.) in EMDEs.
- Participate in collaborative initiatives that seek to catalyse and multiply international efforts relating to supply chains, such as the UN Global Supply Chain Forum, 2022 Supply Chains Ministerial, Transforming Solar Supply Chains Initiative of the Clean Energy Ministerial, various actions outlined G7 Critical Minerals Action Plan and the Supply Chains Mission of the Global Clean Power Alliance (GCPA).
- Support EMDEs to guarantee long-term financial support for their data collection systems. This could include exploring financing models whereby governments receive payment for the data collected from certain categories of users, while maintaining transparency and accuracy. Such mechanisms could benefit both advanced economies, by delivering access to reliable data, and EMDEs, by receiving stable financing to support these data collection processes.
- Leverage the experience of other supply chain data collection processes, including their methods of financing and quality control processes. An example from the realm of agricultural commodity supply chains is Trase; a not-for-profit initiative founded in 2015 with the aim of bringing transparency to deforestation and agricultural commodity trade. Trase provides free-to-download data on agricultural commodity supply chains and sustainability indicators to support transparency and independent analysis.
- Collaborate on data collection processes with industry and academia across the globe. Industry associations and members of the research community are often intimately familiar with the existing data landscape that pertains to their area of expertise. These stakeholders can help identify issues with data and assess where to prioritise efforts.

Box 4. National contributions to amendments of the Harmonized System

Given that every new version of the HS system has a long lead time, which is required to accommodate the necessary international consultation and approvals, and for countries to have time to prepare for adoption of the new codes, the clean energy technology community needs to reflect well in advance about which new technologies are showing the most promise for deployment, and make proposals for new HS amendments to the WCO for the new codes for these technologies well ahead of their mass deployment. Technology-focused scenarios of future deployment, developed by international agencies such as the IEA, the International Renewable Energy Agency (IRENA) or United Nations Industrial Development Organization (UNIDO), among others, may be useful for informing these decisions.

Similarly to for other classification systems, such as the Standard International Energy Product Classification (SIEC), proposals for amendments can include products/technologies that are not yet widely deployed but are expected to increase their penetration significantly in the years to come. In the recent update of SIEC, which is expected to be adopted by the UN Statistical Commission in March 2026, this was the case for (among others) hydrogen-derived fuels including hydrogen-derived methane, hydrogen-derived methanol, and hydrogen-derived gasolines.

For new HS codes to be established, countries need to actively engage in the cycle of amendments. Suggestions for amendments of the HS should be brought to the attention of the national customs administration concerned, or of another intergovernmental organisation that could then ask the WCO Secretariat to place the issue on the agenda of the Harmonized System Committee. Another major source of proposals are intergovernmental organisations which can make proposals on behalf of their members. For either source of proposals, the case for establishing a new code needs to be made by multiple countries for the amendment to be adopted.

Prioritising potential actions to co-ordinate for the Supply Chains Mission

The sections above comprise long lists of potential government actions, some of which are already being undertaken in certain countries. Even if governments wish to pursue all of these actions, they face competing priorities. Table 2 outlines a suggested prioritisation across two categories of potential actions – national and international – as an input to the discussions taking place among those engaging in the Supply Chains Mission of the GCPA.

Table 2 Suggested prioritisation of potential government actions within the timeframe of the Supply Chains Mission

Time horizon	National actions	Desired outcome
Next 6 months	Map all entities in the country responsible for relevant data collection processes.	Provides starting point for all other actions.
	Designate an entity with overall responsibility for co-ordination of data collection efforts. This entity could also be designated to report to international entities.	Avoids duplication of efforts and enables international collaboration.
	Engage in data exchanges with international entities collecting supply chain data, including for confidential data flows under internationally accepted confidentiality rules.	Enables creation of supra-national datasets and international collaboration.
1 year	Invest in development of and updates to mapping for strategically important domestic supply chains.	Provides information on which data on minerals, metals, materials and products needs to be tracked domestically.
	Establish or enhance the regulatory framework supporting clean energy technology supply chain data collection activities.	Establishes legal basis for comprehensive data collection processes that are sustainable over time.
	As an integral part of governmental approval processes, mandate compulsory high-level reporting for all new mining concessions and new production facilities of strategic importance (particularly in EMDEs).	Enables low-cost comprehensive data collection activities.
	Explore or enhance the use of existing administrative data to supplement supply chain data collection.	Provides additional low-cost source of data, using collection processes already established for other purposes, creating efficiencies.
	Conduct comprehensive cost-benefit analysis of subscription to cover a range of governmental needs.	Provides basis for further decision-making to improve cost-effectiveness and coverage of data collection processes.
	Engage in proposing amendments for the HS and other relevant classifications.	Improves comprehensiveness and granularity of information for tracking international trade.

Time horizon	National actions	Desired outcome
2 years	Based on a cost-benefit analysis, decide which data collection activities to house within public entities and for which to use subscription services and external contractors.	Improves cost-effectiveness and coverage of data collection efforts.
	Where possible, aggregate the procurement of subscription services for all governmental needs.	Improves cost-effectiveness and provides the same data basis for all governmental analyses.
More than 2 years	Evaluate if further additions to clean energy supply chain data collection efforts are needed, especially with regards to any technological advances that have taken place.	Ensures data collection processes remain relevant and comprehensive.
Time horizon	**International actions**	**Desired outcome**
Next 6 months	Promote exchange of experiences and best practices among countries through the development of dedicated programmes.	Improves international collaboration, increased comparability of data across countries.
1 year	Assess whether the existing statistical classifications relevant for clean energy technology supply chains reflect all the latest technological developments.	Provides basis for requests for new codes under various relevant classifications.
	Develop viable business models for data collection activities in EMDEs.	Enables data collection activities in countries that may otherwise not be able to develop systems for data reporting.
	Establish collaboration on data collection processes and estimation techniques with industry and academia across the globe.	Improves data quality and comprehensiveness of data collection efforts.
	Engage in processes for proposing amendments to the HS and other relevant classification systems.	Improves comprehensiveness and granularity of information for tracking of international trade.
	Establish and maintain correspondence and interoperability between different classifications as necessary.	Improves coherence and comparability of data collection processes.
2 years	Propose international aggregation of data procurement to support access to commercial data in EMDEs.	Enables access to data in countries that would otherwise not be able to procure them.

Time horizon	National actions	Desired outcome
2 years (continued)	Create a centralised data portal for global clean energy technology supply chain data.	Improves data accessibility, interpretability and transparency. Provides a level playing field for all countries.
More than 2 years	Propose pre-emptive changes to HS and other classifications for pre-commercial stage technologies.	Addresses the long lead time for new HS codes to be introduced by pre-emptive action, thereby improving data relevance and comprehensiveness.

International Energy Agency (IEA)

Unless otherwise indicated, all material presented in figures and tables is derived from IEA data and analysis.

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Typeset in France by IEA - February 2026
Cover design: IEA
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