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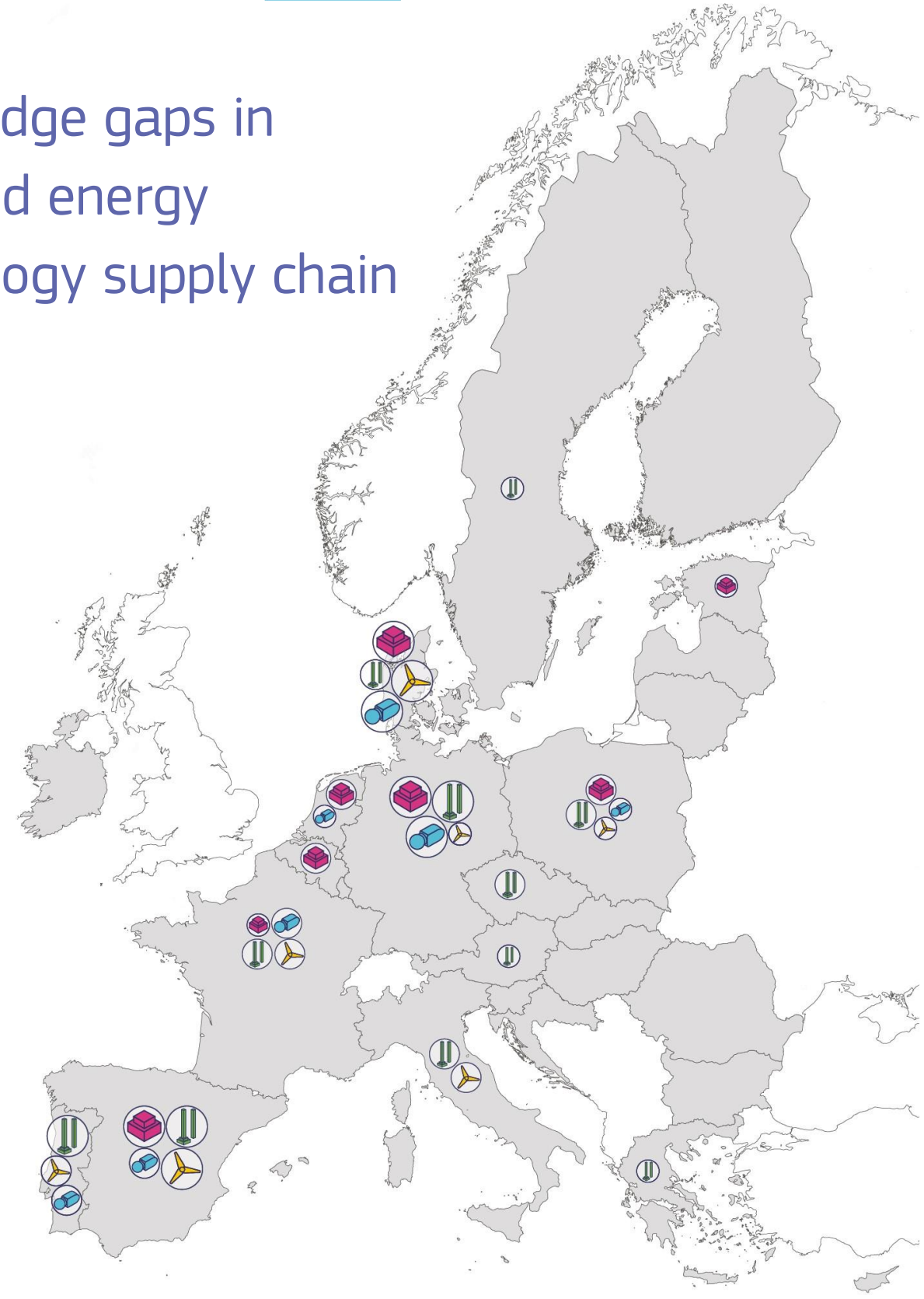
Knowledge gaps in the wind energy technology supply chain



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Abstract

With its potential to provide a clean, abundant, and cost-competitive source of electricity, wind power is playing an increasingly important role in powering homes, industries, and transportation systems. To support the growth of the wind energy sector and enhance the competitiveness of the EU, a robust and resilient supply chain is essential.

The wind energy technology supply chain is an intricate system that involves the coordination of multiple stakeholders, including turbine manufacturers, component suppliers, logistics providers, and installation contractors. This report provides an analysis of the challenges and benefits of mapping the supply chain, highlighting the availability of data sources and the knowledge gaps which must be addressed.

Acknowledgements

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1. Introduction

As the world transitions towards a climate-neutral future, wind energy technology has emerged as a vital component in the global effort to reduce greenhouse gas emissions and mitigate the impacts of climate change. With its potential to provide a clean, abundant, and cost-competitive source of electricity, wind power is poised to play an increasingly important role in powering homes, industries, and transportation systems. To support the growth of the wind energy sector and enhance the competitiveness of the EU, a robust and resilient supply chain is essential.

The European Union's climate and energy policy has evolved significantly in recent years, with the launch of the European Green Deal [1], the Fit for 55 package [2], and the REPowerEU Plan [3]. These initiatives aim to reduce greenhouse gas emissions, increase the use of renewable energy, and improve energy security. The Net Zero Industry Act and the Critical Raw Materials Act are also key legislative proposals that contribute to the EU's climate neutrality objectives by ensuring a stable supply of raw materials essential for renewable energy infrastructure, including wind energy technology. The European Union has set ambitious targets to increase its domestic manufacturing capacity for net-zero technologies, including wind energy, to at least 40% of its annual deployment needs by 2030. Furthermore, the Union aims to become a major actor in the global net-zero technology market, accounting for 15% of world production in value by 2040. To achieve these goals, a deep understanding of the wind energy technology supply chain is crucial.

The challenge of mapping the wind supply chain is complex and multifaceted. The wind supply chain is an intricate system that involves the coordination of multiple stakeholders, including turbine manufacturers, component suppliers, logistics providers, and installation contractors. Understanding the global supply chain dynamics and identifying opportunities for improvement is essential for supporting the growth of the wind energy sector.

The purpose of this report is to provide an analysis of the challenges and the benefits of mapping the wind energy technology supply chain, highlighting data source availabilities and gaps.

The report provides an overview of the wind supply chain, including its global scope and its structure, followed by an analysis of policies related to the supply chain and their potential impact on the industry. The subsequent chapters discuss potential data sources, and present indicative results. The report concludes with a discussion of future work, outlining potential avenues for further research and analysis to continue advancing our understanding of the wind energy technology supply chain. With this comprehensive approach, this report aims to provide a deeper understanding of the challenges and opportunities linked with mapping the wind energy technology supply chain.

2. Supply chain overview

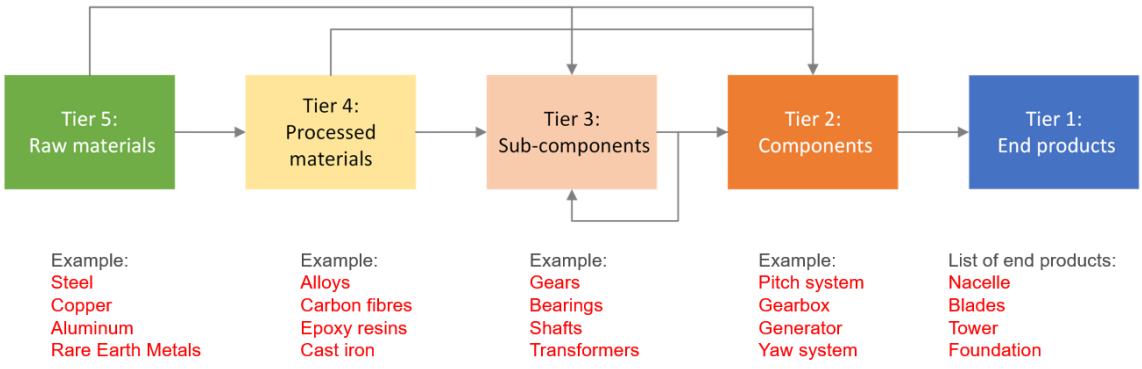
2.1 Global Supply chain dynamics

The global wind energy supply chain is a complex and dynamic system that involves the coordination of multiple stakeholders, including turbine manufacturers, component suppliers, logistics providers, and installation contractors. The supply chain is driven by growing demand for renewable energy, technological advancements, and government policies and incentives. However, the supply chain also faces numerous challenges, including component shortages, logistics disruptions, and quality control issues. As the wind energy market continues to evolve, it is essential to understand the global supply chain dynamics and identify opportunities for improvement.

2.2 Tiering system representation of the supply chain

The wind turbine manufacturing industry uses a tiered supply chain system, similar to other manufacturing industries. This tiered system categorises suppliers based on their products' complexity, the value they add, and their proximity to the final product. Figure 1 shows a general outline of the tiering system for wind turbine components.

Figure 1: Tiering system representation of the supply chain



Source: JRC, 2025

Tier 1 – End products

Tier 1 is at the top of the supply chain and has a direct contractual relationship with the original equipment manufacturers (OEMs), the companies that design and sell the finished wind turbines. These suppliers provide the most critical and complex components that often require advanced manufacturing capabilities and significant R&D investment. Examples of products from Tier 1 suppliers include:

- Nacelle assemblies: The housing for the generator, gearbox, drive train, and other critical components located at the top of the turbine tower.
- Blades: The large aerodynamic components that capture wind energy.
- Towers: The structural components that elevate the turbine's rotor and nacelle above the ground.

Tier 1 suppliers are typically involved in the design phase of new turbine models, working closely with the OEM to develop components that meet specific performance requirements.

Tier 2 - Components

Tier 2 includes less complex components or sub-assemblies for Tier 1 suppliers. They specialise in producing parts that require a high degree of precision but are generally less complex than the systems provided by Tier 1 suppliers. Tier 2 suppliers might provide items such as:

- Gearboxes: Devices that increase the rotational speed from the low-speed rotor to the high-speed generator.
- Generators: Convert the mechanical energy from the rotor into electrical energy.
- Bearings: Critical components that reduce friction between moving parts within the turbine.
- Other components

Tier 2 suppliers often have their own network of suppliers (Tier 3 and below) that provide raw materials or less complex parts required for their components.

Tier 3 – Subcomponents

Tier 3 suppliers are further down the chain and generally produce standard parts. These include:

- Gears
- Bearings
- Shafts
- Other subcomponents

These suppliers may not have direct contact with the OEM but are essential for providing the basic materials and components required by higher-tier suppliers.

Tier 4 – Processed materials

Tier 4 includes all the processed materials used in the manufacturing, such as:

- Permanent magnets
- Alloys
- Resins
- Other processed materials

Tier 5 – Raw materials

Tier 5 focuses on the raw materials used in the manufacturing process, such as:

- Copper
- Steel
- Aluminium
- Rare earth elements
- Other raw materials

In the wind turbine manufacturing industry, the supply chain is not linear, and the tiered structure can be more accurately described as a complex, interconnected, multi-tier supply chain. For instance, a Tier 2 supplier specialising in electronic control systems might not only provide components to Tier 1

suppliers for integration into nacelles, but also directly to Tier 3 suppliers who require sophisticated controls for their subassemblies. Similarly, Tier 5 and Tier 4 suppliers (raw and processed materials) might provide raw materials like steel or composites both to Tier 1 suppliers for direct use in critical components like towers and blades and to Tier 2 suppliers for the fabrication of specific parts. Moreover, a Tier 3 supplier may manufacture part of a subcomponent that is still under Tier 3 (for example the smaller parts of a transformer). This interconnectedness ensures that innovation, efficiency, and quality improvements at any level can propagate throughout the entire supply chain, ultimately benefiting the final product. It also creates a dynamic ecosystem where suppliers across different tiers need to collaborate closely and maintain flexible operations to respond to the shifting demands of the wind energy market.

3. Policies related to the supply chain

The European Union's climate and energy policy has evolved significantly in recent years, marked by the launch of the European Green Deal [1], followed by the Fit for 55 package [2], and more recently, the REPowerEU Plan [3]. The European Green Deal set the overall ambition of achieving a climate-neutral EU by 2050, with a focus on reducing greenhouse gas emissions and increasing the use of renewable energy. Building on this, the Fit for 55 package introduced a series of concrete legislative proposals aimed at reducing net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels.

However, the Russian invasion of Ukraine in 2022 accelerated the need for a more immediate and decisive response to the energy crisis, leading to the launch of REPowerEU. This plan is designed to strengthen the EU's energy security, reduce greenhouse gas emissions, and promote economic growth and job creation.

Specifically for the wind energy sector, REPowerEU sets out ambitious targets to increase the EU's wind power capacity to at least 512GW by 2030, with a specific goal of installing at least 60 GW of new wind energy capacity per year between 2027 and 2030. This represents a significant increase from the current (2021-2024) rate of around 10-18 GW per year. REpowerEU is supporting the growth of the wind energy sector to develop a strong and resilient supply chain for wind energy equipment, including turbines, blades, and other components.

The increasing demand for wind energy technologies poses significant challenges for the sector's supply chain. To address these challenges, as well as broader supply chain vulnerabilities, the European Union has introduced two key pieces of legislation: the Net Zero Industry Act (NZIA) [4] and the Critical Raw Materials Act (CRMA) [5].

NZIA is building on the momentum created by REPowerEU, by creating a favourable environment for the development and deployment of net-zero technologies, and addressing the specific challenges faced by the wind energy sector in terms of supply chain development. Its measures include the creation of a new wind energy manufacturing fund, which will provide financial support to wind energy manufacturers in the EU, as well as initiatives to improve the skills and training of the workforce in the sector. NZIA will also help to promote the development of new wind energy technologies, such as floating wind and larger turbines, which will be essential for the EU to meet its climate and energy goals.

By 2030, the European Union aims to significantly increase its domestic manufacturing capacity for net-zero technologies, such as wind power, to at least 40% of its annual deployment needs, which is equivalent to 42 gigawatts per year. This ambitious goal is part of the Union's broader strategy to achieve its 2030 climate and energy targets.

In the longer term, the EU seeks to claim a significant part of the global net-zero technology market, aiming to account for 15% of world production in value by 2040. Furthermore, it has established guidelines to ensure that sustainability and resilience are integral to its decision-making processes. Specifically, Member States will be required to give significant weight to sustainability and resilience when evaluating bids for contracts, with these criteria carrying a minimum weight of 5% and a combined weight of between 15% and 30% of the total award criteria. This means that bidders will need to demonstrate a strong commitment to sustainable and resilient practices to be competitive.

CRMA is focusing on diversifying the European Union's supply of critical raw materials necessary for its strategic industries and sectors. It is designed to address the EU's dependency on imported critical

raw materials such as rare earth elements, aluminium, nickel, iron and steel, and others that are vital for the green and digital transitions and for defence and space applications.

While the supply chain of critical raw materials is, for most materials, outside the EU (e.g., rare earth elements) [30, 31], CRMA is designed to enhance the extraction, processing and recycling of critical raw materials within the EU. The Act also emphasises the need for improved circularity and sustainability in handling these materials, setting the stage for a more resilient and environmentally responsible supply chain. Articles 28 and 29, for example, ensure that permanent magnets and other components are designed and constructed to be recyclable. The wind industry is required to minimise electronic waste and reduce the environmental impact of wind turbines as well as recycle the REE used to manufacture these magnets.

A key component of CRMA is the establishment of a strategic stockpiling system. This system aims to create reserves of essential raw materials, thereby providing a buffer against potential supply disruptions that could affect the wind energy sector. By maintaining a stockpile of critical materials, the EU can enhance its preparedness for supply chain shocks, ensuring that the production and deployment of wind energy infrastructure can continue uninterrupted, even in times of market volatility or geopolitical tensions. In this was CRMA is expected to reduce the EU's strategic dependencies, bolster economic growth, and support the creation of new jobs within the Union.

The NZIA and CRMA policies contribute to the EU's climate neutrality objectives by ensuring a stable supply of the raw materials essential for renewable energy infrastructure, including wind energy technology. Through these initiatives, the EU is proactively addressing current and future supply chain vulnerabilities, while upholding rigorous sustainability and environmental protection standards.

4. Potential data sources

The following list of data sources used for supply chain mapping is not intended to be exhaustive, and the inclusion of data providers should not be interpreted as an endorsement or recommendation by the JRC. This compilation is focused solely on the specific application of these data sources for supply chain mapping purposes and does not constitute a review or evaluation of the overall quality, features, or suitability of the products or services provided by these sources. The information presented is a snapshot of the current status of these data sources at the time of our research.

Our aim in sharing this information is to provide insight into our knowledge and experience in utilising these data sources for supply chain mapping, highlighting their potential value and usefulness in this specific context, and to facilitate further exploration and discussion among stakeholders. By presenting this information, we seek to contribute to the collective understanding of the tools and resources available for supply chain mapping, without implying any preference or guarantee regarding their performance or effectiveness.

4.1 Open access data

International Electrotechnical Commission (IEC) certification standards relating to equipment for use in renewable energy applications (IECRE)

The IEC system [6] aims to ensure the safety, performance, and reliability of wind energy equipment. The IEC 61400 series of standards, specifically designed for wind turbines, covers aspects such as design, testing, and certification of wind turbines, as well as the safety and performance of wind turbine systems. Certification to IEC 61400 standards verifies that wind turbines meet the required safety and performance criteria, including structural integrity, electrical systems, and control systems. This certification provides assurance to manufacturers, operators, and regulatory bodies that wind turbines are designed and manufactured to operate safely and efficiently, reducing the risk of accidents and downtime. By adhering to IEC 61400 standards, wind turbine manufacturers can demonstrate their commitment to quality and safety, while also facilitating international trade and market access.

The IECRE Wind Turbine Type Certificates contain valuable information that can contribute to the mapping of the supply chain. The certificate provides details on the wind turbine's design, manufacturing, and testing, including the major components, such as blades, towers, and electrical systems. This includes insights into the supply chain structure, including the relationships between manufacturers, primary and secondary suppliers, and subcontractors. For instance, the certificate's list of major components can help identify key suppliers, while the manufacturing and testing information can reveal the locations and capacities of various manufacturing facilities. This information can be used to create a detailed map of the supply chain.

The components typically covered by the certificates are the following:

- Blade (tier 1)
- Blade bearing (tier 3)
- Pitch system (tier 2)
- Main shaft (tier 3)
- Main bearing (tier 3)
- Gearbox (tier 2)
- Yaw system (tier 2)
- Generator (tier 2)
- Converter (tier 3)
- Transformer (tier 3)
- High-voltage switchgear (tier 3)

One of the primary advantages of using IECRE Wind Turbine Type Certificates to map the supply chain is that these certificates provide a standardised and globally recognised framework for evaluating the safety and performance of wind turbines. This standardisation enables the creation of a consistent and reliable dataset, which can be used to map the supply chain and identify key components, suppliers, and manufacturing facilities.

The certificates contain information on the specific components and suppliers involved in the wind turbine's design and manufacturing. Suppliers are reported at a company level rather than per specific manufacturing location. This can make it difficult to create a comprehensive map of the supply chain and may require additional data sources to fill in the gaps.

COMEXT and COMTRADE

COMEXT [7] and COMTRADE [8] are two comprehensive databases that provide detailed information on international trade. COMEXT is a database maintained by Eurostat, the statistical office of the European Union, which contains data on the EU's external trade in goods with non-EU countries. The database provides detailed information on trade by country, product, mode of transport, and type of goods, and is available from 1988 onwards. Similar databases are maintained by national statistical offices in other countries, providing trade statistics for their respective regions.

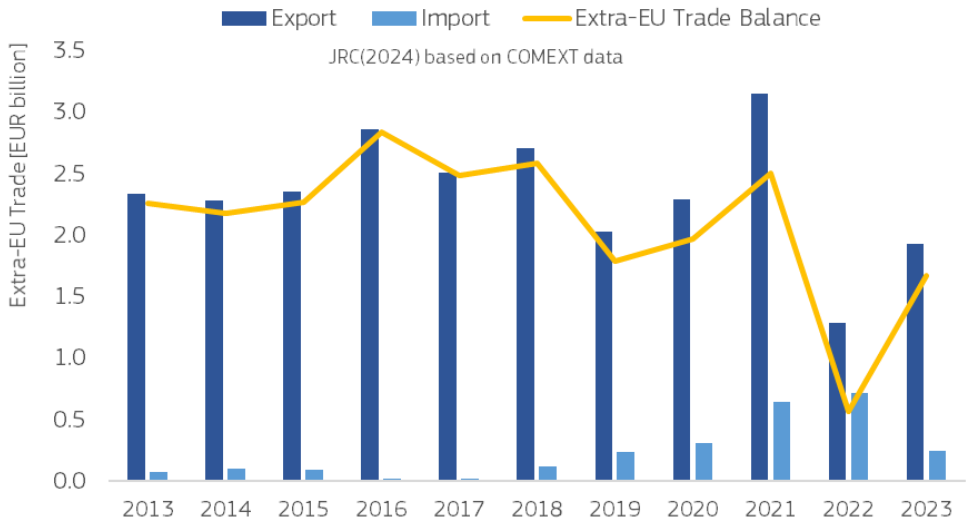
COMTRADE is a database maintained by the United Nations Statistics Division, which provides data on international trade in goods and services for over 170 countries. The database contains information on bilateral trade relationships, trade by product, and trade in services, and is available from 1962 onwards. Both databases are widely used by researchers, policymakers, and businesses to analyse international trade patterns, identify trends, and inform trade policy decisions. They serve as valuable resources for understanding global trade and its implications for the economy.

COMEXT and COMTRADE provide information on specific trade codes related to some wind turbine components. The existing exclusively relevant trade code, 850231, which corresponds to "Generating sets, wind-powered", provides an opportunity to track the international trade of wind turbines and related components. Other wind turbine components are classified in broader categories that include components used in different sectors. Using as an example Wind turbine towers, there is currently one Harmonised System (HS) code sub-heading covering towers and lattice masts of iron or steel: "7308 20 - Towers and lattice masts of iron or steel". This sub-heading is quite broad, since it includes

other applications as well and does not enable the collection of trade data referring to the wind towers, which are experiencing an increasing level of international trade following the growing deployment of wind turbines. Revising trade codes is a complicated and time-consuming process; therefore, at present, deriving information from trade data can only be done through disaggregation to extract relevant information. The disaggregation procedure requires careful analysis and interpretation of the data to ensure accuracy and reliability.

By using data from COMEXT and COMTRADE databases, we can gain insights into the global trade patterns of wind turbines, including the countries of origin and destination, trade volumes, and values. This information can help identify key actors in the wind energy supply chain, track the movement of wind energy technologies, and analyse the impact of trade policies on the industry. For instance, the COVID-19 pandemic and subsequent post-pandemic constraints have visibly affected global trade patterns, as is evident in the 2022 sharp reduction in Extra-EU trade for wind generating sets, shown in Figure 2. This sharp reduction illustrates how global events and trade disruptions can impact the wind energy industry, highlighting the importance of monitoring trade data to understand the intricacies of the global supply chain. In Figure 2, the Extra-EU trade for wind generating sets and trade balance are presented as an example.

Figure 2: Extra-EU trade for wind generating sets [EUR bllion].



Source: Adapted from JRC(2024) [9]

The data can be used to identify the role of key economies in the wind energy supply chain, analyse trade patterns, and understand the impact of trade policies on the industry. Additionally, the data can be combined with other sources of information to gain a more comprehensive understanding of the wind energy supply chain.

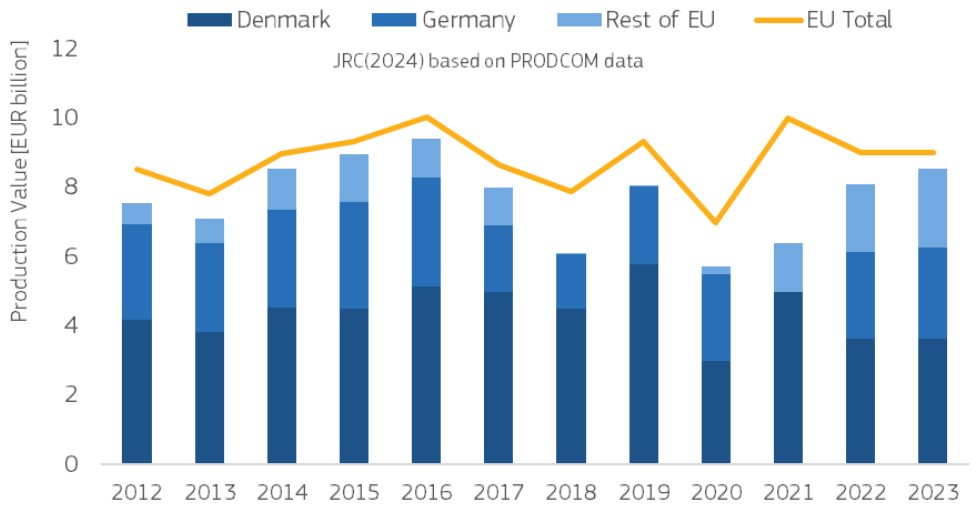
The information is reported at country level and does not identify specific companies or entities involved in the trade, nor does it capture domestic production or consumption. Additionally, the data is also subject to the "Rotterdam effect", where trade flows are distorted by the transhipment of goods through major ports such as Rotterdam, making it challenging to accurately determine the true country of origin or destination.

COMTEXT and COMTRADE can provide a partial view of the wind energy supply chain, but additional sources of information are needed to gain a more complete understanding of the industry. This can partially be covered by customs data that would include a more detailed description of the shipment, as well as more detailed information on the full route of the shipment at company level.

PRODCOM

PRODCOM (PRODucts COMmunity) [10] is a database maintained by Eurostat, the statistical office of the European Union. It collects detailed information on the production of goods and services in various industries across EU Member States, as well as in Norway, Iceland, and Switzerland. The database provides a harmonised, comprehensive view of economic activity within the EU and its associated countries, helping policymakers, businesses, and researchers to make informed decisions and understand the structure of manufacturing and service industries. The system is based on a hierarchical structure similar to the COMTRADE data base, with each product being assigned a unique code. This similarity in coding structure, along with corresponding concordance tables, enables the comparison and reconciliation of data between COMTRADE, which focuses on international trade, and PRODCOM, which focuses on production within the EU and associated countries. Despite the limited availability of specific production codes related to wind energy, similarly to COMTRADE, PRODCOM can have a role in mapping the wind energy supply chain. The one existing relevant production code 28112400 (Wind turbines - Generating sets, wind-powered), provides an opportunity to track the domestic production of wind turbine generating sets within the EU. By using data from PRODCOM, we can gain insights into the European production patterns of wind turbines, including the manufacturing countries, production volumes, weights and values. This information can help identify key actors in the wind energy supply chain, track the flow of wind energy technology components, and analyse the impact of domestic policies and trends on the industry. Figure 3 presents the EU production value and top producers among the Member States which disclose data as an example.

Figure 3: EU production value and top producers among the Member States disclosing data [EUR billion].



Source: Adapted from JRC (2024) [9]

The data can be used to identify the role of key countries in the EU wind energy supply chain, analyse production patterns, and understand the impact of domestic policies and trends on the industry.

Additionally, the data can be combined with other sources of information to gain a more comprehensive understanding of the wind energy supply chain.

PRODCOM data are reported at country level and by production codes, which, similar to COMEXT and COMTRADE, may not specifically identify wind turbine components. This makes it difficult to identify the production of components such as blades, towers, or control systems, which are not specifically coded. Furthermore, the data does not provide information on the specific companies or entities involved in the production, nor does it capture international production.

4.2 Databases available with membership

ITC Trade Map

Trade Map [11] is an online platform that provides access to international trade data, offering a range of tools and resources for the analysis of trade flows, tariffs, and market access conditions. The platform provides detailed statistics on trade in goods and services, including information on export and import volumes, trade balances, tariff rates, and concentration of suppliers. It also comprises a list of importing and exporting companies under each trade code and additional categories (see Table 1), distinguishing their role as importer, exporter, producer or distributer and the additional products and services traded by the company. Access to some of the services need a registration or small fee depending on the location and status of the user.

The information in Trade Map can help identify the origin and destination of goods, as well as the companies, countries and industries involved in the supply chain. Additionally, Trade Map provides data on trade in value-added, which can help to identify the countries and industries that contribute to the production of a particular good or service. The platform also offers data on intra-industry trade, which can help to identify countries' relative strengths and weaknesses in different industries and products. Furthermore, Trade Map's data on trade by mode of transport, such as sea, air, and land, can help to identify the logistics and transportation patterns of goods, while data on trade by product and HS code can help to track the movement of specific products through the supply chain.

Table 1: Number of importing companies in Denmark, broken down by product categories, for the following product: 850231 Generating sets, wind-powered

Product category	Number of importing companies available in Trade Map
Converters, rotary	6
Electric and electronic equipment for industrial use (wholesale)	1
Electric generator sets	38
Generators, wind energy, over 100 kW	6
Importers-exporters, audio-visual (AV) equipment	1
Importers-exporters, electrical and electronic products	1
Micro generators, wind energy, under 100 kW	6
Telecommunications equipment (wholesale)	1

Source: ITC Trade Map (2025)

The strengths of using Trade Map data include its comprehensive and up-to-date coverage of international trade data, which provides a picture of global trade flows and patterns, as well as the information on the companies trading under the relevant codes. Additionally, the platform's data on

trade in value-added and revealed comparative advantage can help to identify the countries and industries that contribute to the production of a particular good or service, providing valuable insights into the supply chain and dependencies introduced by the concentration of suppliers.

As it relies on trade data, Trade Map inherently uses the existing trade classifications. This means that data may be reported in different classification systems or reporting requirements and source datasets, which have not been harmonised (note categories listed in Table 1). The list of importing and exporting companies includes companies who have voluntarily registered to the underlying datasets [12], [13].

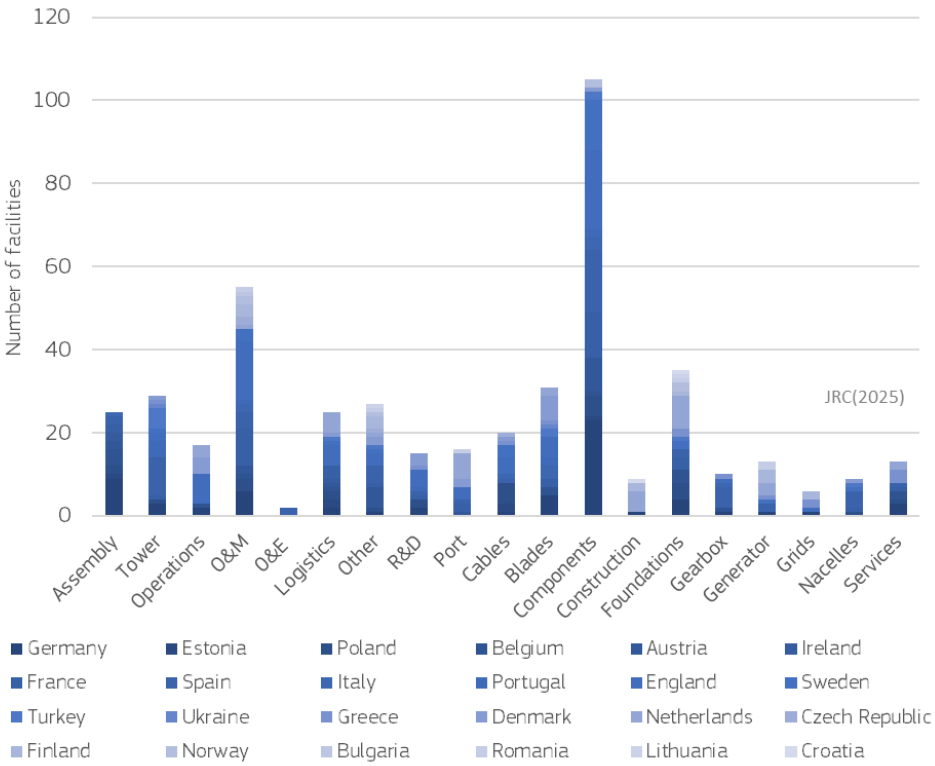
WindEurope Intelligence platform

WindEurope [14] is the leading trade association for the wind energy industry in Europe, representing over 600 member companies active in more than 35 countries. The organisation's main goal is to promote the use of wind power in Europe, advocating for policies and regulations that support the growth of the industry and the transition to a low-carbon economy.

WindEurope's Intelligence platform includes a wide variety of data, statistics and reports for wind energy in Europe. This includes – but is not limited to – data on deployments, energy production, financing, auctions, turbine orders, and permitting.

WindEurope has highlighted supply chain issues through dedicated reports and interactive maps. An example of such analysis is presented in Figure 4, showing the number of manufacturing plants by host country across Europe. This is a comprehensive database for Europe covering manufacturing plants, including their locations, company names, and respective sectors of activity. It provides a solid foundation for understanding the landscape of the industry.

Figure 4: Number of manufacturing plants in Europe, by country, and supply chain segment they are active in



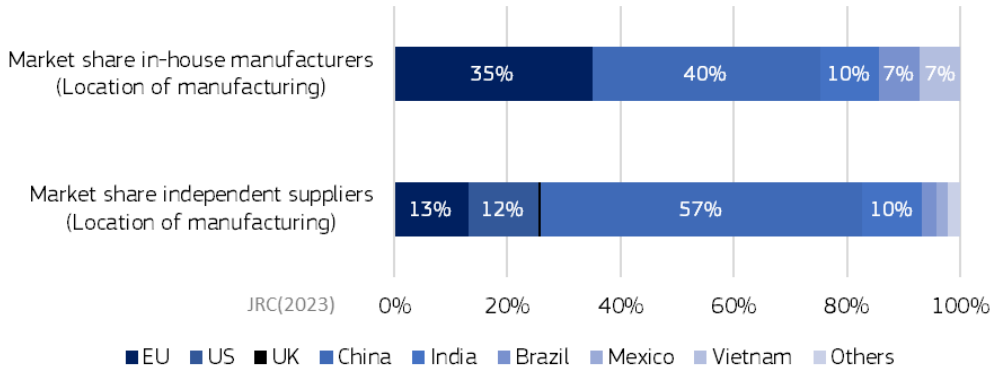
Source: JRC analysis based on WindEurope, 2025

Global Wind Energy Council (GWEC)

The Global Wind Energy Council (GWEC) [15] database is a comprehensive repository of information on the global wind industry. It provides access to a wide range of data and statistics on wind energy trends, including installed capacity, market shares, policy frameworks, and industry developments. The database covers wind energy data from over 100 countries, offering insights into regional and national markets, as well as global trends. With regular updates and in-depth analysis, the GWEC database serves as a valuable resource for industry stakeholders, policymakers, and researchers seeking to understand the evolution and growth of the global wind energy sector.

The GWEC database contains a range of data relevant to mapping the global wind energy supply chain, primarily through its 'Market Data & Statistics', 'Supply Side Data', and other modules. The 'Supply Side Data' module provides insights into the global wind industry manufacturing footprint, including data on turbine suppliers, component manufacturers, and their respective market shares (see example of analysis in Figure 5). This is complemented by 'Country Profiles', which offer an overview of the wind energy market in various countries, including key statistics, policies, and industry developments. The 'Market Outlook' and 'Auctions & Tenders' modules provide additional context on the demand side, helping to identify opportunities and trends in the global wind energy market.

Figure 5: Estimated market share of in-house and independent generator manufacturers by location of manufacturing



Source: Adapted from JRC, 2023 [16]

One of the key advantages is the comprehensive and up-to-date information on turbine suppliers, a selection of component manufacturers, and their respective market shares. This enables users to identify key actors and trends in the global wind energy supply chain. Additionally, the database's country profiles and market outlook provide a detailed understanding of the demand side, allowing for an analysis of the interplay between supply and demand in different markets. The database's coverage of auctions and tenders also provides insights into the competitive landscape of the industry.

4.3 Commercial data sources

BloombergNEF (BNEF)

BNEF [17] is a provider of clean energy and technology research, data, and analysis. As a subsidiary of Bloomberg, BNEF relies on the company's financial and data expertise to deliver insights and information on the clean energy, energy technology, and sustainability sectors. The data and analytics platform provides information on the global clean energy landscape, including market trends, policy developments, company, and project-level data.

One of the key datasets available through BNEF is the manufacturing capacity of nacelles, which provides detailed information on the nacelle manufacturers and their capacity globally. A total of 187 nacelle manufacturing plants are reported in the database. Additionally, BNEF's database includes a comprehensive list of companies active in the wind supply chain, including their respective contributions to the various components of a wind turbine, such as blades, towers, generators, gearboxes, and control systems. As of the latest update, the database contained a total of 10 981 companies related, in some capacity, to the wind energy sector. Filtering for companies actively engaged in the manufacturing of wind energy technology components returned a total of 1 251 companies. This can be refined further by excluding firms, such as project developers, that primarily deal with the management of wind farms.

The BNEF database provides particularly valuable insights into the manufacturing capacity of nacelles. It offers a foundation for supply chain mapping of this component and enables the identification of major manufacturers and their capacities. Additionally, the database includes a comprehensive list of companies active in the wind supply chain, including their respective contributions to various components of a wind turbine, such as blades, towers, generators, gearboxes, and control systems.

The Wind Power

The Wind Power – Wind Energy Market Intelligence [31] is a database providing quantitative and qualitative data for the wind energy sector. It includes data from a variety of actors in the industry worldwide, including wind farm developers, operators, owners, turbine manufacturers, and other stakeholders. It offers access to information about regions, countries, manufacturers, types and numbers of turbines, hub heights, MWs/GWs, developers, operators, owners and commissioning dates, making it a valuable source of data for the wind energy sector.

By analysing the data, relationships between companies can be identified, such as the suppliers of critical components. The database's comprehensive coverage of global companies and smaller actors in the sector make it a valuable tool for understanding the relationships that underpin the wind energy supply chain.

Rystad Energy

Rystad Energy [18] offers an integrated energy database which provides a wide range of data and analytics on the oil and gas industry, the renewable energy industry, and the energy transition. The database includes detailed information on oil and gas fields, production and exploration projects, companies, and assets, as well as data on offshore wind, solar, and other renewable energy sources. It also includes financial and operational data, such as production costs, revenues, and emissions.

Rystad Energy's database provides a comprehensive set of data relevant to supply chain mapping of wind energy technology, including detailed information on offshore and onshore wind farms, turbines, and components. The database tracks the ownership and operational relationships between different

assets, allowing users to map the supply chain from turbine manufacturing to project development and installation. Specific data points include wind farm data, such as location, capacity, and installation dates, as well as information on turbine models, manufacturers, and suppliers. Additionally, the database provides data on the supply chain of key components, such as blades, towers, and nacelles, and tracks the relationships between wind farm developers and OEMs.

One of the primary advantages is the database's extensive coverage of wind farms, turbines, and components, allowing users to track the specific deployment of each wind turbine model. The data is also highly granular, with detailed information on turbine models, manufacturers, and suppliers, which enables users to identify specific relationships and dependencies between companies.

FactSet

FactSet [19] is a global financial data and software company that provides data feeds and analytics solutions. The FactSet database is a repository of financial data, analytics, and content that covers a wide range of asset classes, including equities, fixed income, commodities, and currencies. It aggregates data from various sources, including exchanges, regulators, and other third-party providers, to offer a unified platform for data analysis. The database provides access to real-time and historical market data, company financials, estimates, ownership, and other key metrics, as well as tools for risk management.

FactSet's database offers detailed company profiles, financials, and ownership structures, enabling the identification of key actors across the supply chain, from manufacturers of turbines and blades to suppliers of raw materials and components. In theory, provided that a particular industry segment is well populated, by analysing the data, relationships between companies can be identified, such as the ownership structure of a turbine manufacturer, the suppliers of critical components such as bearings or gearboxes, and the origin of raw materials such as steel or rare earth minerals.

Moody’s Orbis

Orbis [20] is a comprehensive database on private companies provided by Moody’s. It covers both publicly traded and private companies, providing access to detailed financial information, such as income statements, balance sheets, and cash flow statements, as well as data on company ownership, management, and industry classification, and business intelligence on over 400 million companies worldwide. Users can screen companies based on criteria such as sector, type of activity, geographic location, industry, revenue, and profitability.

The database offers detailed information on companies involved in the wind energy sector, including turbine manufacturers, component suppliers, and raw material providers. Orbis data can be used to identify key actors in the supply chain, track ownership structures, and analyse financial performance and industry trends. Specifically, Orbis provides data on companies' product and service offerings, allowing researchers to identify suppliers of critical wind energy components, such as blades, towers, and gearboxes. Additionally, Orbis data on company ownership and subsidiaries can help map the complex relationships between companies in the wind energy sector, including joint ventures, partnerships, and mergers and acquisitions.

Pitchbook

PitchBook [21] is a financial data and software company that provides real-time data, research, and analysis on the venture capital, private equity, and mergers and acquisition markets. Its platform offers a comprehensive database of companies, investors, and deals, as well as tools for tracking market trends.

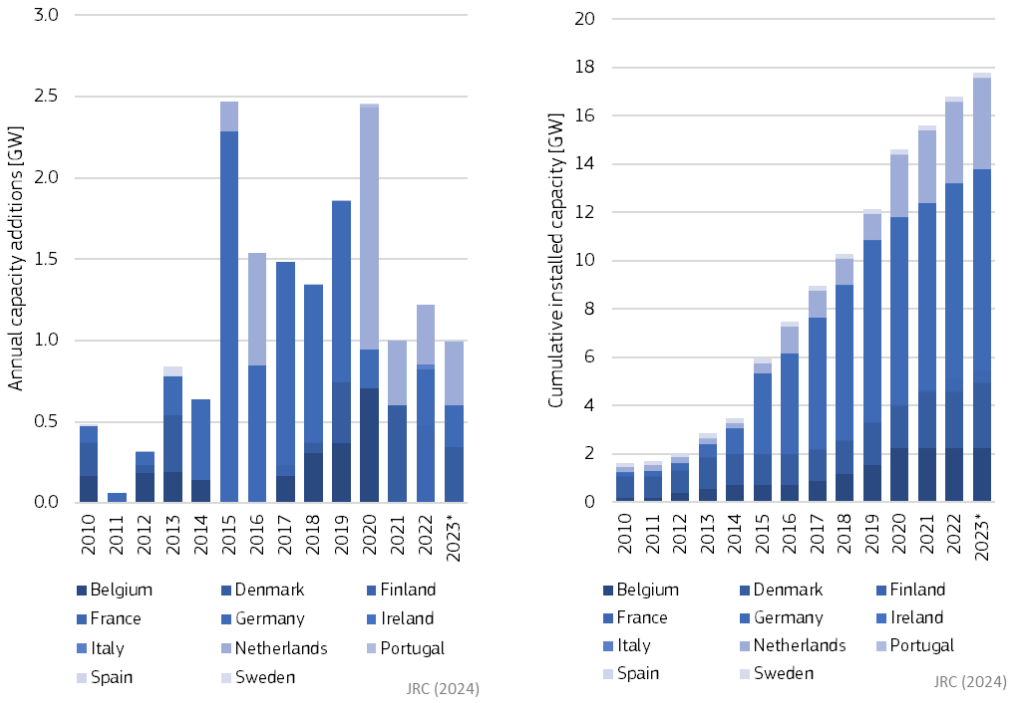
PitchBook data can be used to identify key actors in the supply chain, track investment trends, and analyse financial performance and market dynamics. Specifically, PitchBook provides insights into companies' funding rounds and valuations, enabling researchers to identify suppliers of essential wind energy components. Additionally, PitchBook data on mergers and acquisitions, investor networks, and executive contacts can help map the intricate relationships within the wind energy sector, including joint ventures, partnerships, and strategic alliances.

PitchBook's coverage of global companies and investment activities is primarily focused on private equity and venture capital investments. These companies represent one part of the wind energy supply chain, alongside smaller, privately held companies or those that are not actively seeking funding.

4C Offshore

4C Offshore [22] provides a comprehensive database with detailed information on the offshore wind industry, covering the entire sector from developers and project owners to turbine manufacturers, foundation suppliers, and installation contractors. The database includes information on project timelines, capacity (e.g. see **Figure 6**), location, and technology, as well as company profiles, financial data, and market research reports. It also tracks deployments, turbine manufacturers, installation contractors and vessels, maintenance providers, and project developments, enabling users to map the offshore wind supply chain, track market trends, and analyse the competitive landscape. The database further tracks ownership and operational relationships between different assets, the pipeline of new projects, and auctioning volumes for offshore wind energy assets, making it possible to identify key market drivers and trends through regularly updated data.

Figure 6: EU offshore wind energy capacity additions (left) and installed capacity (right), GW.
Note: (*) Preliminary data at the end of 2023.



Source: Adapted from JRC, 2024 [23]

The database provides detailed information on turbine manufacturers and installation contractors, as well as project developments and timelines. This enables users to gain a detailed understanding of the complex network of relationships between companies and projects, and to identify key actors and market trends. Additionally, 4C Offshore's data is updated regularly, ensuring that users have access to the most current information on the industry.

S&P Global

S&P Capital IQ, S&P Connect and Global Trade Analytics Suite (GTAS) [24] are platforms offered by S&P Global, providing data and analytics to support investors, developers, and operators.

S&P Capital IQ and S&P Connect provide data relevant to supply chain mapping of the wind energy sector including detailed information on deployments, such as global and regional wind installation trends, project pipelines, and capacity additions. The platforms also offer data on manufacturing capacities, including production volumes, capacity utilisation, and supply chain disruptions for key wind turbine components such as blades, towers, and generators. Additionally, the datasets cover technology costs, including levelised cost of energy (LCoE) benchmarks, turbine pricing, and balance of plant (BOP) costs, as well as commodity prices for key materials such as steel, copper, and rare earth metals. Furthermore, the platforms provide insight into the competitive landscape, including market share analysis, supplier profiles, and partnerships. Other relevant data points include inventory levels, shipping and logistics information, and production forecasts for key components.

A key strength of these platforms lies in the granularity of the data. For instance, there is detailed information on manufacturing capacities and production volumes, while technology cost data can inform decisions on component sourcing and procurement. Additionally, the platforms' coverage of the wind energy sector, including data on deployments, project pipelines, and market trends, provides an extensive view of the industry.

GTAS provides an array of trade data, including detailed trade statistics, transactional shipment records, and forecasts of global trade activity. The data encompass a wide range of factors, such as trade volumes, commodity values, and transportation modes, allowing users to gain a deeper understanding of certain global trade patterns and trends.

These data and particularly bills of lading, which are available for a number of reporting countries, can be used in supply chain mapping to track the movement of goods, identify key suppliers and buyers, and visualise the flow of commodities between these countries and regions and their trade partners.

4.4 Reports

4.4.1 Literature in the public domain

Wind turbine Life Cycle Assessments (LCAs)

Life Cycle Assessments reveal the environmental impacts of a product or system throughout its entire life cycle, from raw material extraction to end-of-life disposal or recycling. LCAs are typically based on a standard (for example ISO 14040/44 standard) and provide a comprehensive analysis of the environmental impacts of a wind power plant, including energy and material inputs, emissions, and waste generation.

The data provided by LCAs are highly relevant to mapping the supply chain, as they offer a detailed breakdown of the various stages involved in the production of wind turbine components, from raw

material extraction to manufacturing, transportation, and end-of-life treatment. This includes information on the use of primary materials, such as steel, iron, aluminium, and concrete, as well as descriptions of the manufacturing processes used to produce turbine components. For example, the LCAs for selected Vestas wind turbines are published in [25].

LCAs offer a valuable framework for calculating material inputs [26] and connecting the material tiers of the supply chain to component tiers.

4.4.2 Commercial reports – business intelligence

Adamas Intelligence – Rare Earth Magnet Market Outlook to 2040

The Adamas Intelligence - Rare Earth Magnet Market Outlook to 2040 [27] is a comprehensive market research report that provides a detailed analysis of the global rare earth magnet market. It provides a detailed overview of the global NdFeB alloy, powder, magnet, metal and magnet rare earth oxide markets, including a breakdown of historical production, consumption and prices from 2015 to 2023. It also offers a 20-year forecast of the market's growth prospects, trends, and outlook, covering key areas such as demand and supply dynamics, pricing, and trade flows.

The report provides a list of companies in the magnet production market and a detailed and comprehensive list of active and future mines along with their production capacities. The overview of the magnet market segment also provides insights into demand (broken down by technology) and supply (new mines or reserves by country), possible bottlenecks and the substitution landscape.

Permanent magnets are one of the most critical components for wind turbines, particularly for offshore wind, with a very volatile market dominated by China.

5. Overcoming data gaps in supply chain mapping

Mapping the wind energy supply chain is a complex task that requires a thorough understanding of the intricate relationships between various stakeholders, including manufacturers, suppliers, and logistics providers. One of the primary challenges in mapping the supply chain of wind energy is, as presented in Chapter 4, the absence of a single, comprehensive source of data that provides complete information on the entire supply chain. Instead, various sources offer partial data, with each tier of the supply chain having its own unique set of available information. For instance, Tier 1 suppliers, which provide components directly to wind turbine manufacturers, may have readily available data on their production capacities and supply relationships. However, as we move down the supply chain to Tier 2 and Tier 3 suppliers, the availability and quality of data decreases significantly.

The heterogeneity of data across different tiers of the supply chain poses a significant challenge in connecting the dots and filling in the gaps. The basic challenge is to develop a methodology that can integrate the available information, reconcile the differences, and provide a comprehensive view of the entire supply chain. To overcome this challenge, one approach would be to start with the Tier 1 suppliers and gradually move down the supply chain, connecting each tier to the next. In doing so, the aim would be to identify the key relationships, dependencies, and information gaps that exist between different tiers, and develop a more complete and accurate picture of the wind energy supply chain.

A tier-by-tier approach will systematically address any data gaps and inconsistencies and develop a robust and reliable methodology to map the supply chain. By starting with Tier 1 and iteratively connecting it with Tier 2, before moving on to subsequent tiers, the emerging comprehensive, and detailed map of the wind energy supply chain will provide valuable insights into the complex relationships and dynamics that shape this critical industry. A similar approach was followed by Dumont & Varela-Irimia [28] where the FactSet database was used to provide a proof-of-concept, limited supply chain mapping of the wind industry.

However, it is unlikely that complete and robust data for every aspect of the supply chain will be available. Therefore, it is essential to identify potential workarounds and develop strategies to address potential data gaps. This may involve making informed assumptions, using proxy data, or developing alternative methodologies to estimate missing information. Identifying and addressing these gaps will aid the development of a robust and reliable approach to mapping the supply chain and provide a comprehensive understanding of the wind energy industry.

5.1 Developing a set of assumptions to address data gaps

One way to overcome issues of data availability and quality is to make informed assumptions that can help to increase the comprehensiveness of the supply chain map. These assumptions will inevitably introduce some degree of uncertainty, but they are necessary to develop a working methodology. They may include the following.

Based on location

- When a company is producing a component in-house, we may attribute deployments to specific manufacturing locations based on company information and proximity to the deployment location. This is based on the assumption that companies are likely to manufacture and deploy turbines close together, where possible, to reduce transportation costs and increase efficiency.

— We can assume that companies will try to source components from local suppliers whenever possible, to reduce their logistics costs and increase their responsiveness to changing market conditions.

— If a company uses a particular supplier for a specific component in one region, we may assume that they use the same supplier for that same component in other regions, if it is available. This is based on the idea that companies tend to establish long-term relationships with suppliers and use them across multiple regions to reduce costs and increase efficiency.

Based on company relationships

— If a company is using the same suppliers for a component across all known wind turbine certificates, we can extend these suppliers to all wind turbine models of the same sub-technology of that company. This assumption is based on the idea that companies tend to establish long-term relationships with suppliers and use them across multiple product lines to reduce costs and increase efficiency.

— We can assume that companies use standardised components across similar product lines (e.g. the same generator at a different hub height) to reduce costs and increase efficiency.

Based on trade

— We may disaggregate the available data on trade and production to estimate the flow of components and materials through the supply chain. This may involve using industry benchmarks, averages, or other proxy data to estimate the proportion of components sourced from different suppliers.

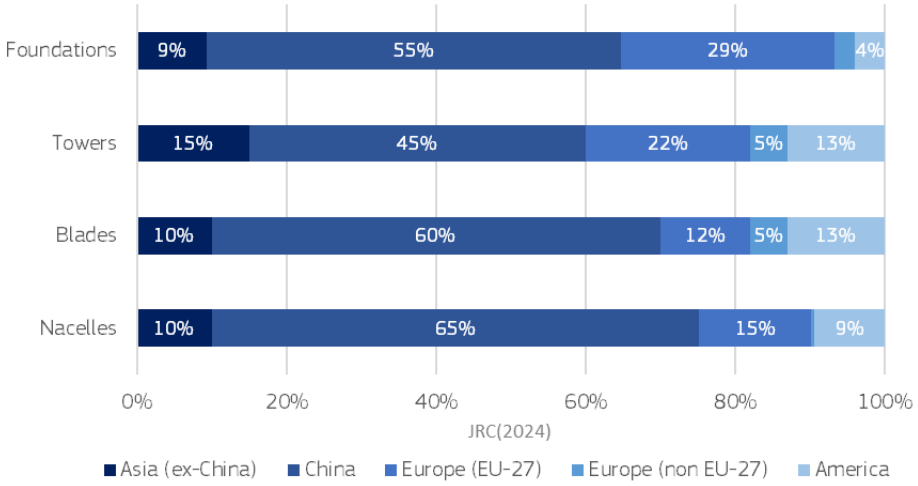
Applying the assumptions above will increase the completeness of the supply chain map, albeit with limitations and uncertainties. In order to create a robust mapping, each assumption must be adequately justified for the specific part of the supply chain it will apply to, providing transparent information about the data sources and methodologies used in the supply chain mapping. This will enable users to understand the potential limitations and uncertainties of the mapping, and to make informed decisions based on the insights and information provided.

5.2 Examples of mapping selected parts of the supply chain

Mapping manufacturing capacities

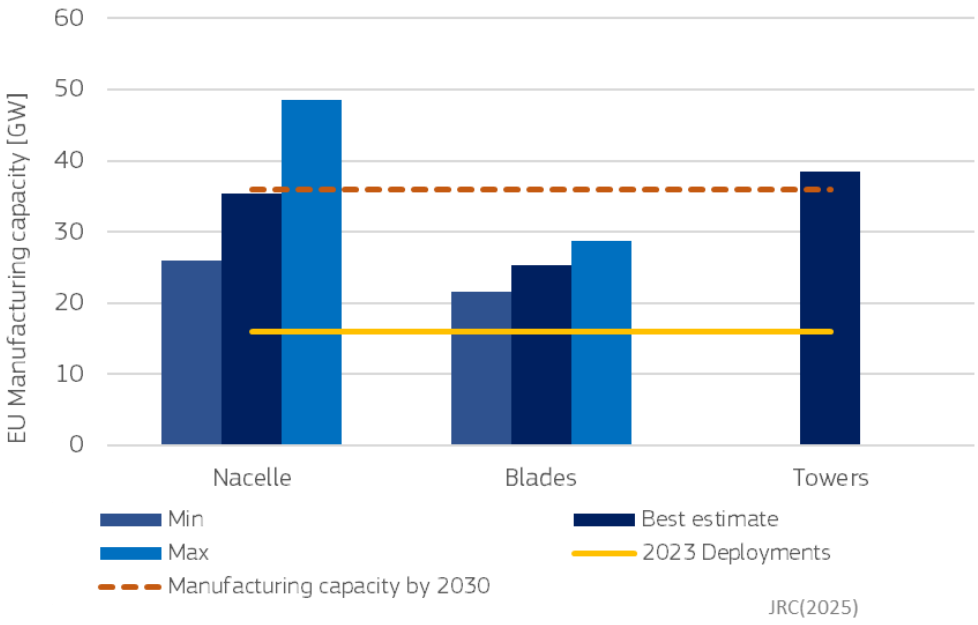
By combining information from sources described in Chapter 4, we can have a robust view of component manufacturing capacities. Figure 7 and Figure 8 present an indicative synthesis of information on the distribution of the global and EU manufacturing capacity of major wind components. As multiple sources of information are available, the values can vary, so a range can be established to account for best and worst case scenarios. Figure 9 presents a map of manufacturing locations per component in the EU.

Figure 7: Global manufacturing capacity of key wind components.



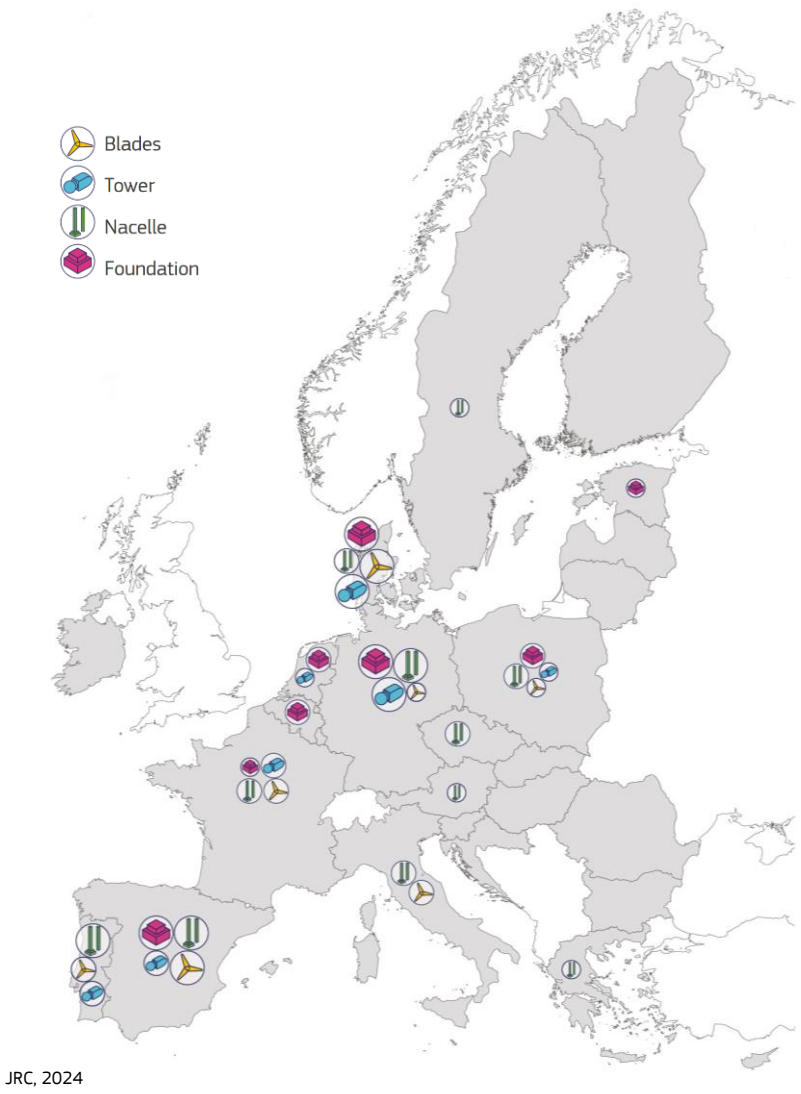
Source: Adapted from JRC, 2024 [9]

Figure 8: Indicative analysis of manufacturing capacities in the EU



Source: JRC elaboration of various sources, 2025

Figure 9: European wind energy manufacturing locations (2023)
Note: Larger circles indicate more manufacturing output.

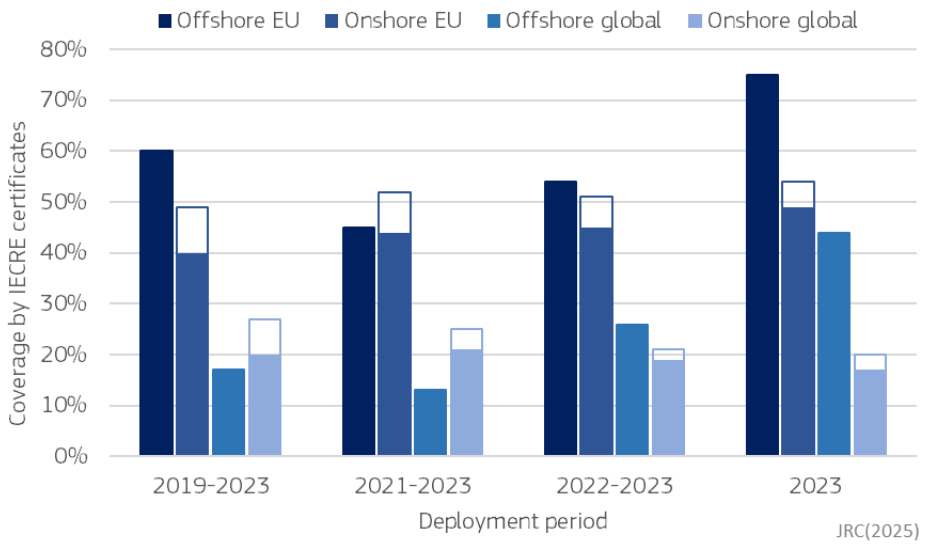


Source: Adapted from JRC, 2024 [29]

Utilising IECRE certificates

IECRE certificates are one of the few sources that can be used to establish supplier-customer relationships. Even though the certificates provide information covering a wide range of Tier 2 components and some Tier 3 components, they are available for a limited amount of wind turbines (currently amounting to 47 wind turbine models). This provides partial coverage considering the total deployments in the EU and globally in the past five years (see Figure 10). One way to address this is to consider some wind turbine models as proxies for others, for example with the same generator but a different tower height. In this way, the coverage of the available certificates increases by up to 6 percentage points for onshore deployments (see Figure 10).

Figure 10: Percentage (%) coverage of deployments by IECRE certificates with (contour line) and without (solid colour) using proxies for wind turbine models



Source: JRC based on IECRE certificates, 4c Offshore and Rystad, 2025

Using ITC Trade Map and COMTRADE to assess trade contribution

As mentioned in Chapter 4, exclusive trade codes only exist for wind generating sets. By using Trade Map we can identify companies that trade under this specific code and a specific product category, in this case 'Generators, wind energy, over 100 kW'. For this product category, 116 exporting and 46 importing companies are available in Trade Map. For each one of these companies, it is possible to identify other trade codes used to import sub-components and export components. For example, one observation from Trade Map is that companies active in the product category 'Generators, wind energy, over 100 kW' are also active as importers in the product category 'Wind energy production equipment parts and accessories', under the trade code: '850239 Generating sets (excl. wind-powered and powered by spark-ignition internal combustion piston engine)'. Mapping these connections between trade codes for companies active in the sector and combining them with the COMTRADE data can provide some insights into supply chain interactions in the wind energy industry.

Using bills of lading and detailed customs data to identify trade flows between companies

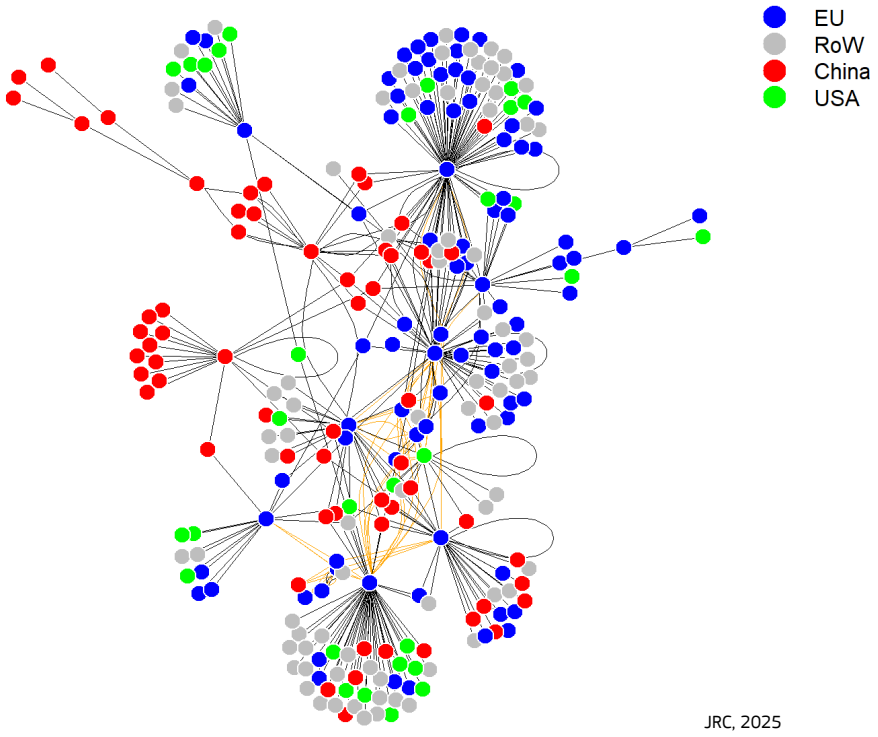
A bill of lading is a document issued by a carrier (such as a shipping line, freight forwarder, or logistics company) to a shipper (the party sending the goods). It describes the cargo in more detail than just the trade code, and outlines the terms of transportation, including the route, mode of transport, and delivery instructions. It acknowledges all players in the transport chain – the sender, the handler, the importer and the final recipient – which makes them very useful when mapping the supply chain. For example, if company A produces a component in country X, exports to company B in EU country Y, which in turn forwards the shipment to Company C in EU country Z, we are able to identify that company A supplies company C from Country X to country Z, while other trade data register the shipment in country X which was the first recipient and the point of entry in the EU.

Using trade connections between companies to analyse the supply chain network

The wind energy technology sector is a complex system of interconnected companies that supply, manufacture, and distribute wind turbines, components and the raw materials needed to manufacture them. Knowledge of the structure of this network is critical, as it enables us to analyse the supply chain, identifying dependencies, bottlenecks, inefficiencies, and opportunities for improvement.

By combining information from the sources presented in Chapter 4, as well as insights from other sources, a basic network of connections can be constructed between companies in the wind sector. Figure 11 presents an indicative network of interconnections between companies along the wind energy supply chain. Certain nodes emerge as more important, by having a commercial relationship with more companies in the sector.

Figure 11: Example of supplier-customer relationships of (Tier1-Tier 2-Tier 3) companies from the EU (blue nodes), China (red nodes) and other countries (grey nodes). Connections are coloured by the main source stating the relationship.



Source: JRC based on various sources, 2025

6. Conclusions

This report provides a comprehensive overview of the challenges, opportunities, and knowledge gaps in mapping the wind energy technology supply chain. As the EU pursues ambitious climate and energy targets a robust supply chain becomes increasingly critical to ensuring security of supply, industrial competitiveness, and technological innovation.

The wind energy supply chain is inherently complex and multilayered, involving diverse actors across different tiers—from raw material extraction to final turbine assembly. Mapping this supply chain presents unique difficulties, largely due to the fragmentation and inaccessibility of data across tiers and product categories.

Nevertheless, this report has demonstrated that partial but meaningful mapping is possible through the integration of multiple data sources, including open-access databases, commercial intelligence platforms, trade records, and company disclosures

Chapter 5 contains an approach that can be used to develop a methodology to address the challenges of mapping the wind energy supply chain. Making informed assumptions and using a tier-by-tier approach can increase the comprehensiveness of the supply chain map. Applying this approach can connect and integrate data from all available sources to construct a supply chain map that captures the complex relationships and dynamics of the wind energy industry.

Such an undertaking could focus on several key areas, including:

- Data integration: Data from multiple sources, including industry reports, company websites, and trade databases, can be combined to create a comprehensive picture of the wind energy supply chain.
- Supply chain visualisation: The supply chain can be represented in a clear and intuitive way, highlighting key relationships and dependencies between companies and components.
- Analysis and insights: The supply chain map can be analysed to identify key trends, patterns, and insights, including areas of concentration, bottlenecks, and opportunities for improvement.
- Validation and verification: The robustness of the supply chain map can be checked using a combination of industry expert feedback, company verification, and data validation techniques.

A comprehensive supply chain map of the wind energy industry would be a valuable resource for various stakeholders, including industry, policymakers, and researchers. It could provide a detailed understanding of the complex relationships and dependencies within the industry, identifying key areas of concentration and bottlenecks, as well as areas of opportunity and risk. It will offer a unique dataset for analysing trends, patterns, and insights in the wind energy industry, to gain a deeper understanding of the industry's dynamics, identify areas for further investigation, and develop new hypotheses and research questions. It can inform and shape policy decisions that support the growth and development of the wind energy industry, ultimately contributing to a low-carbon economy and a sustainable energy future. These decisions could include:

- developing strategies to support the development of domestic supply chains, reducing reliance on international imports and promoting local economic growth,
- creating policies that promote competition and innovation within the industry, driving down costs and improving efficiency,

— developing policies that support the integration of wind energy into the broader energy system, including grid infrastructure and energy storage,

— monitoring and evaluating the effectiveness of existing policies and programmes, making data-driven decisions to optimise their impact.

The map could also facilitate international cooperation and knowledge sharing, as policymakers from different countries can learn from each other's experiences and best practices, and work together to address common challenges and opportunities.

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List of abbreviations and definitions

Abbreviations	Definitions
BNEF	BloombergNEF
CRMA	Critical Raw Materials Act
GWEC	Global Wind Energy Council
IEC	International Electrotechnical Commission
IECRE	IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications
LCOE	Levelised Cost of Energy
LCA	Life Cycle Assessment
NZIA	Net Zero Industry Act
OEM	Original Equipment Manufacturer

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