Geoeconomics of Green Hydrogen

Assessing the EU‘s current position in resilience and export potential

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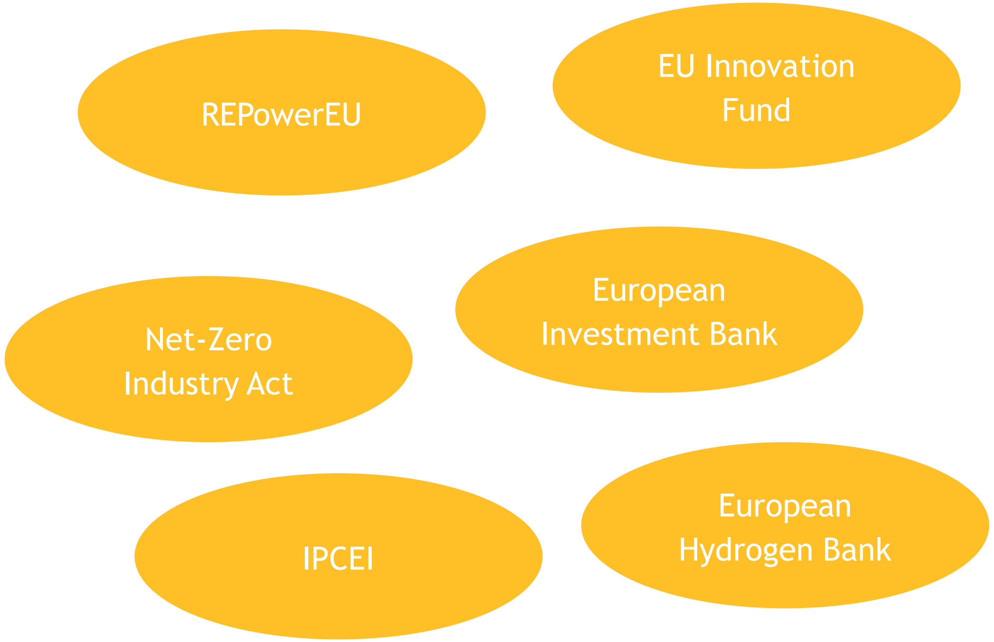
The EU has designed policy instruments to support its geoeconomic position along the hydrogen value chain

Policy instruments supporting the EU's green hydrogen economy



Geoeconomics of the hydrogen value chain & policy instruments

- The geoeconomics of energy can substantially change with a ramp-up of a green hydrogen economy, as green hydrogen can potentially be produced anywhere.
- To this end, the EU and other regions of the world, are implementing large-scale industrial policy programs. Subsidies are often a main element.
- These policy instruments aim at reducing import dependencies while at the same time reshoring value creation.
- In this analysis, we focus on selected policy instruments of the EU along the green hydrogen value chain and assess preconditions for achieving the goals mentioned above.
- This analysis can support a prisonization of public funds. The arguments regarding value creation and export potential rely on the assumption of competitive free markets.

EU‘s current preconditions for a hydrogen economy characterized by import dependencies and high domestic production costs

	Import shares (without political intervention)	Import diversification	Relative production costs	Export potential	Selected Policy Instruments
Hydrogen	**Currently:** High for natural gas as input for hydrogen production **Expected:** High if demand increases as planned	**Currently:** no meaningful imports of hydrogen. **Expected:** Potentially high, due to various potential import sources.	**Currently:** No market established **Expected:** High transport costs can leave market share for European production	**Currently:** No market established **Expected:** Low, as EU exhibits high production costs and potentially higher demand than production capacity	A variety of instruments is applied to increase domestic production and diversify future imports
Electrolyser	**Currently:** Low, as international trade is limited **Expected:** High, if demand evolves as planned	**Currently:** Low **Expected:** Potentially high, due to various potential import sources.	**Currently:** High, costs are four times higher than Chinese competitor **Expected:** High, potential learning rates unlikely to change fundamental difference	**Currently:** Unclear, as quality advantages of EU-producers might compensate for higher production costs **Expected:** Low, if quality differences matter and do not remain	
Wind turbines	**Currently:** Low **Expected:** Low, if local manufacturing capacity remains due to high international transport costs	**Currently:** Unclear, as import share is low **Expected:** Unclear, as market dynamics depend on worldwide demand	**Currently:** High **Expected:** High	**Currently:** Low, as transport costs pose a constraint to long-distance trade **Expected:** Low, as high relative production costs and transport costs can favor local-for-local production	The NZIA supports investments in manufacturing capacity
PV modules	**Currently:** High **Expected:** High	**Currently:** Low, as most PV-manufacturing capacity in the world is in China. Expected: Low	**Currently:** High **Expected:** High	**Currently:** Low, as manufacturing capacity is small compared to demand in EU **Expected:** Low, additional demand can be absorbed by cheaper non-EU production	
Critical raw materials	**Currently:** High	**Currently:** Mixed with some low diversification	**Currently:** No significant production in EU	**Currently:** Not applicable due to neglibile reserves	The CRMA formulates diversification goals and defines strategic projects

1

Motivation and Background

Global energy trade relations expected to change from concentrated fossil reserves to integrated value chains.

Current energy dependencies

- Fossil fuels dominate energy supply with energy **resources concentrated** in a few world regions. The EU exhibits a high reliance on a limited number of countries for energy imports.
- **Energy security concerns** arise due to an import dependency on limited sources. This also implies strategic risks regarding vulnerabilities due to geopolitical tensions.
- Economies in the EU traditionally relied on importing energy as an input for value chains **with high value creation**. This business model requires not only sufficient quantities of energy imports, but these imports need to be available at world-competitive prices.

Potential future developments in a hydrogen-based economy

- **Renewable energy (RE)** resources, essential for producing green hydrogen, are geographically more widespread than fossil resources. With electrolysers, infrastructure, electricity, and water available, hydrogen can be produced anywhere, enabling a **larger degree of energy-independence**.
- The potential shift in global energy trade could open up **new opportunities for value creation** as well. However, this shift is likely to also induce **changes in existing energy demand**, as energy in the EU is expected to become **more expensive.**[4]
- The EU is implementing policy measures to position itself in this potential future geoeconomic situation.

How is the EU positioned in this future economy currently and in a future economy? How is the economic policy designed?

1: eurostat (2024) | 2: SWP (2023) | 3: Global Solar Atlas | 4: EWI (2024)

Industrial subsidization is gaining track. How to maneuver a changing global industrial political environment?

Trade-offs between economic and security policy issues

- The shift to clean energy involves trade-offs between economic goals and energy security, especially concerning energy resilience.
- Transitioning from fossil fuels to renewables can strengthen energy security by cutting reliance on imports, but this requires significant investment.
- Effective strategies must balance economic growth with stable, resilient energy supply chains.

Beginning subsidy competition

- Countries are ramping up subsidies to attract investment and speed up clean tech innovation, sparking a global "subsidy race."
- This competition aims to secure clean tech supply chains and create jobs, often competing for the same resources like skilled workers and investors.
- Subsidies are becoming vital tools for governments, leading to a revival of protectionist trade policies.

How and what to subsidize when funds are limited?

- In an environment of limited financial resources, Europe must be strategic in how it uses subsidies to support energy transition.
- Simply matching the subsidies provided by larger economies may not be feasible.
- Instead, Europe might need to prioritize high-impact sectors and invest either in areas where it has a competitive edge or where resilience issues demand subsidization.

We use indicators to evaluate the current situation allowing for assessment of potential effects of policy measures

To gain insights into how to maneuver a changing global industrial political environment we will investigate three areas of interest

Current and expected import dependencies until 2030	
Domestic production and imports today	Future production potential

Expected relative manufacturing costs in EU		Expected export potential	
Market Growth	Competition	Profitability	Maturity

Selected policy Instruments to increase investment activity		
Obstacles	Policy Goals	Policy Instruments

- In the following of the analysis, we investigate these three areas, that together form an understanding of the geoeconomics of the energy transition:
  1. Current and expected import dependencies until 2030
  2. Expected relative manufacturing cost & Expected export potential
  3. Policy instruments that affect the discussed areas.
- In the first area, we investigate shares of domestic production to imports and the potential for future production.
- We further introduce the second area on the next slide. Especially the four key indicators *Market Growth*, *Competition*, *Profitability, and Maturity* will be discussed with regard to how they help understand expected export potential.
- In the third area we look at various determined obstacles and how policy instruments aim at addressing these obstacles.

We use four key indicators to evaluate the expected export potential in each market.

Expected Export potential

Market Growth

- Market growth indicates rising demand for products and services in a region.
- High growth suggests potential for exporters to capture a larger market share.
- It signals scalability opportunities for exporters to increase volumes and revenues.
- Regions can specialize further as demand expands.

Competition

- Market crowding indicates potential challenges.
- Lower competition may offer easier market entry.
- High competition requires differentiation.
- In saturated markets, export potential may be lower or require differentiation.
- Limited competition suggests an untapped or emerging market, offering new export opportunities.

Profitability

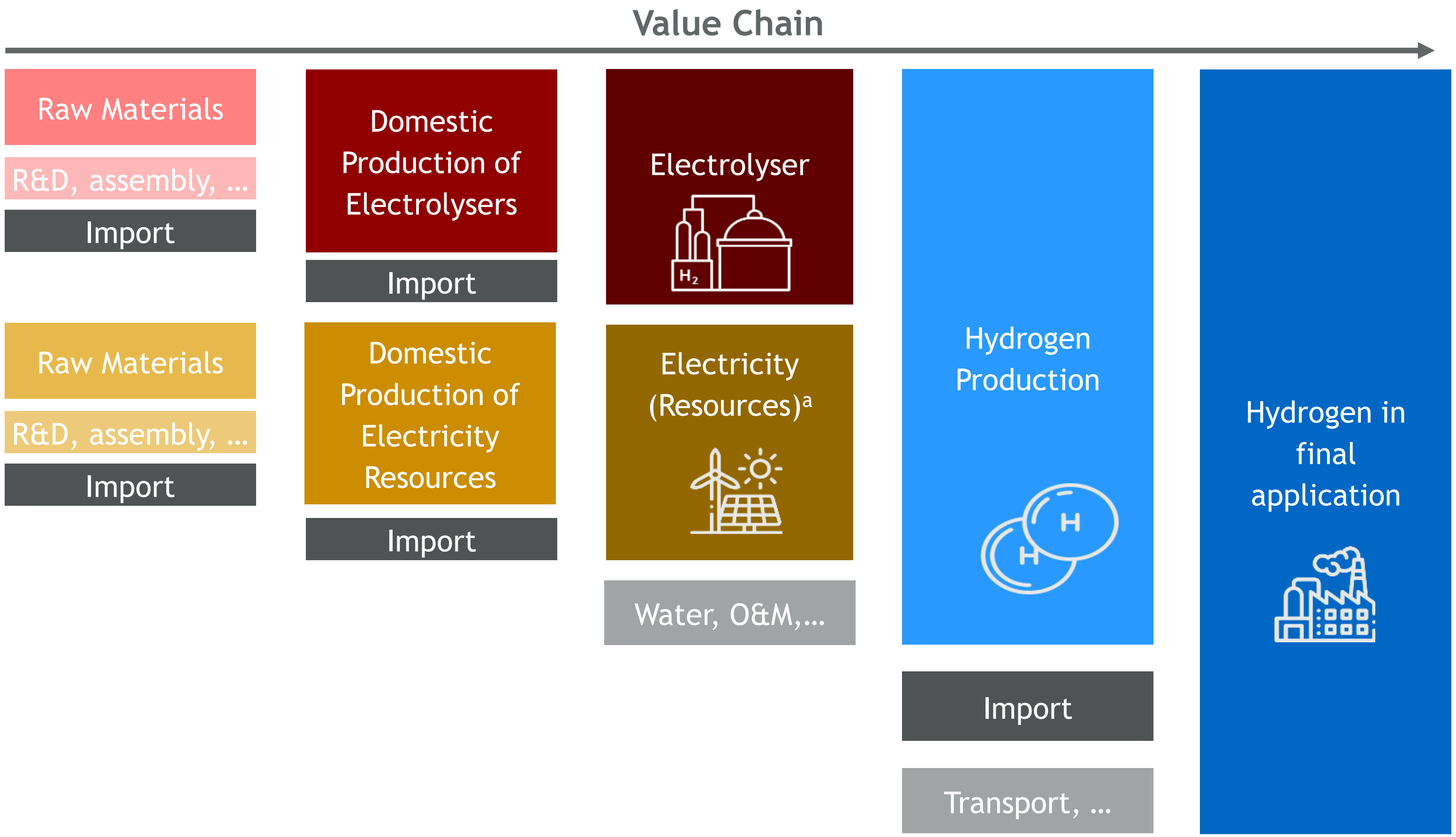
- Profitability indicates a market's competitiveness and potential export returns.
- Key factors to analyze include labor and raw materials.
- High profitability markets generally support new entrants.
- High profitability enhances export potential and encourages long-term viability.

Market maturity and risk

- Market maturity and risk reflect market stability and potential challenges.
- Mature markets are stable but often saturated.
- Emerging markets offer growth but come with higher risk.
- This analysis helps understand the trade-off between opportunities and potential economic or regulatory challenges.

These four dimensions together provide a comprehensive view of an economy's export potential in a given market by assessing demand, global competition and profitability.

Each step of the hydrogen value chain has unique conditions for independence and value creation in future geoeconomics.



The hydrogen value chain

- Delivering hydrogen to its final application requires various upstream activities in the value chain. Reducing import dependencies at a certain stage requires the domestic provision of the preliminary step(s) of the value chain.
- This analysis focuses on the value chain from hydrogen production to raw materials.
- On each level of the value chain, main questions arising are:
  - What is the status quo concerning trade relations and import dependencies?
  - What is the future supply potential?
  - Which countries could be **key trade partners**?
  - How could international **dependencies** shift?

Annotations: The overview is qualitative only. | a: As renewable electricity is generated locally, the resources for electricity generation (e.g., PV and wind power plants) are considered in this step.

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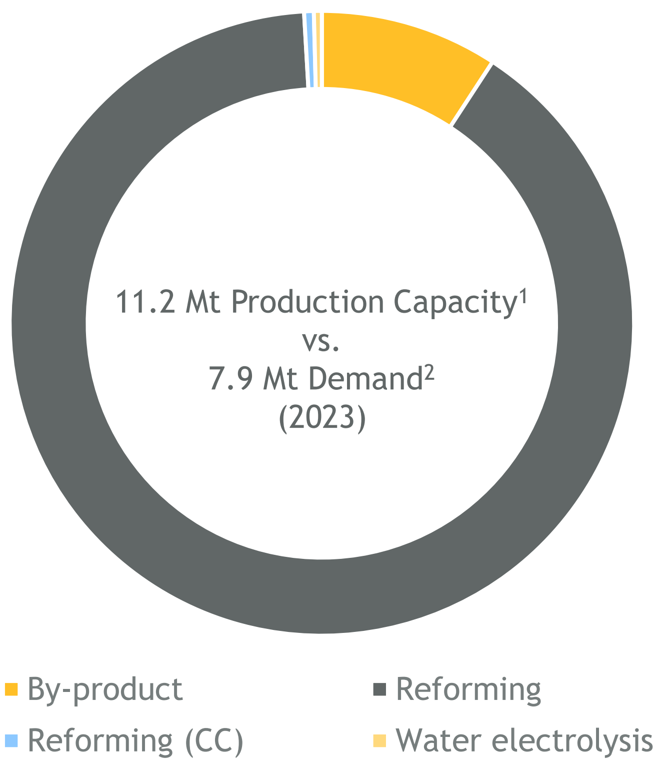
Hydrogen Production

Most hydrogen is currently domestically produced from fossil fuels. Electrolysis and CCUS are needed for net-zero targets.

Domestic[a] Hydrogen Production Capacity 2023



Domestic production and imports today

- Currently, hydrogen demand is primarily met by domestic production. The majority of 97% is consumed by the industry sector[b] much of which is produced on-site. A negligible amount of hydrogen is imported from outside Europe.[1]
- Hydrogen production capacity in Europe stands at approximately 11.2 Mt annually, while demand is around 7.7 Mt per year.[2] A small minority of hydrogen is produced via water electrolysis (<1%) whereas most is produced as a by-product (9%) or via reforming (90%), which primarily relies on natural gas.[1, 3]
- This highlights that although there is production capacity for hydrogen, import dependencies on natural gas remain.[5] In 2023, the EU imported 87 % of its natural gas consumption.[6]

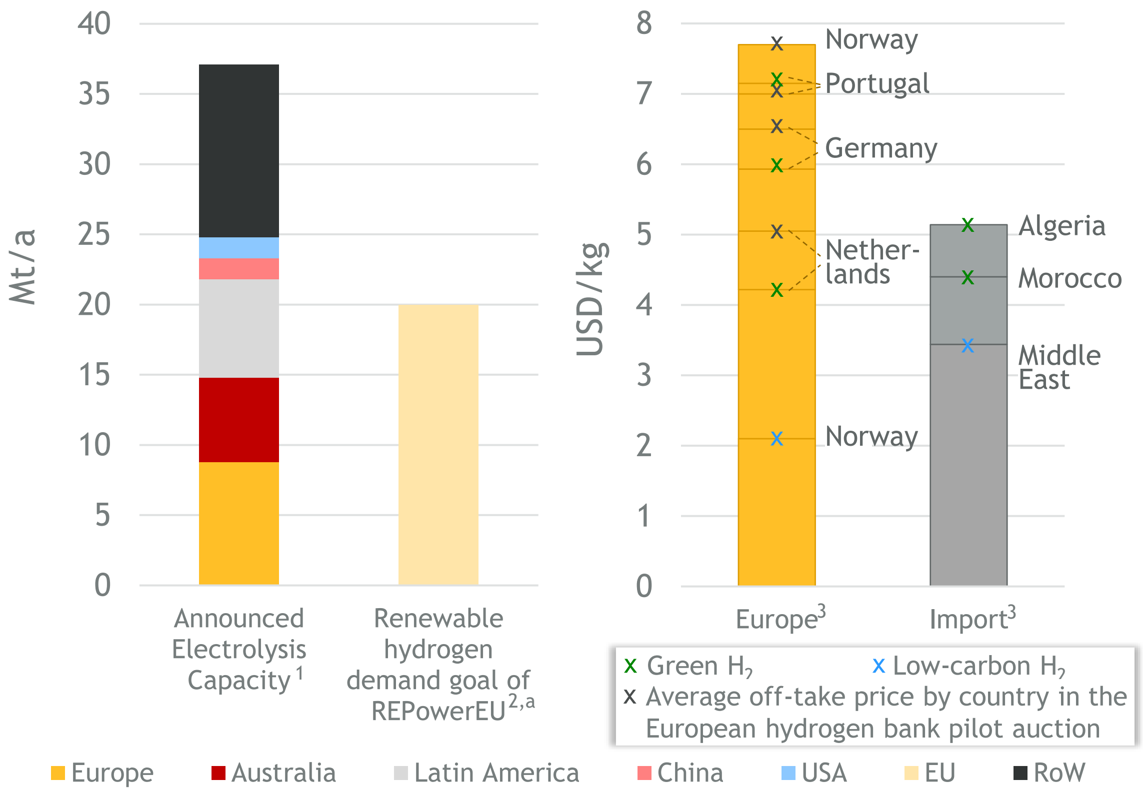
Future production potential

- Mid- to long-term goal is the replacement of fossil hydrogen generation and ramp-up of green hydrogen production.[7]
- By 2030, Europe's annual low-emission hydrogen production could reach approx. 8 Mt through electrolysis (excluding early-stage projects: >5 Mt) and over 3.5 Mt via fossil fuels with carbon capture utilization and storage, CCUS (excluding early-stage projects: >3 Mt).[8] If all projects are realized, this would match current hydrogen production capacity. Even if only later-stage projects are considered, current demand could be met, though significant demand increases are expected.

a: EU27, United Kingdom, Iceland, Liechtenstein, Norway and Switzerland | b: The production of ammonia, methanol and other chemicals as well as industrial heat and refining are considered. | 1: European Hydrogen Observatory (2023) | 2: European Hydrogen Observatory (2023) | 3: Di Nardo et al. (2024) | 5: EWI (2023) | 6: Strategic Perspectives (2024) | 7: FfE (2024) | 8: IEA (2024)

Hydrogen demand and production capacity are expected to rise significantly. However, substantial imports are still anticipated.

Announced electrolysis capacity, total REPowerEU green hydrogen demand goal and cost of low-carbon hydrogen supply to Germany by origin in 2030



- **Market growth:** The global low-emission hydrogen market could reach USD 112 billion by 2030 under the NZE scenario, with demand largely driven by decarbonizing industrial uses.[1, 4] Announced clean hydrogen consumption in Europe is rising from 0.23 Mt in 2024 to 7.13 Mt in 2030.[5]
- **Competition:** Australia, Latin America, the USA, and China are emerging as competitors in low-carbon hydrogen production, with China dominating electrolysis capacity today and North America potentially supplying over 50% of exports by 2030.[1, 6] However, due to lower production costs and its proximity, Morocco may become a key exporter for Europe.[7] Major scenarios imply partial hydrogen imports being cost-effective for Europe.[8,9]
- **Profitability:** Although green hydrogen production cost is expected to decrease significantly, it generally remains more expensive than low-carbon hydrogen.[4] As shown in the graph, green hydrogen from some European countries (e.g., the Netherlands) may be cost competitive with imports. Nonetheless, profitable production remains limited in many countries without subsidies or carbon pricing.
- **Market maturity and risk:** While traditional hydrogen production methods are mature, green hydrogen is in the "Early Adoption" phase, facing technological, regulatory, and infrastructure challenges.

1: IEA (2024) | 2: European Commission (2022), Goal: produce 10 Mt renewable hydrogen domestically and import another 10 Mt | 3: Production cost of green hydrogen based on EWI (2024): Estimated cost to produce 100 TWh (volatile) using the most cost-effective RES. Production cost of low-carbon hydrogen based on McKinsey (2023). Transport cost based on EWI (2024): The least expensive route available to Berlin, Germany. Average off-take price (main off-taker) by country in the European Hydrogen Auction from European Commission (2024) | 4: McKinsey (2023) | 5: Hydrogen Europe (2023) | 6: BNEF (2024) | 7: Plank et. al (2023) | 8: Agora Energiewende and Agora Industry (2024) | 9: IEA (2022)

Addressing main issues in green hydrogen supply through funding, strategic partnerships and regulatory reform.

REPowerEU Objective: “Setting a target of 10 million tonnes of domestic renewable hydrogen production and 10 million tonnes of imports by 2030, to replace natural gas, coal and oil in hard-to-decarbonise industries and transport sectors.”[1]

Obstacle	Policy Goal	Selected Policy Instrument
High production costs	Reduce production costs to lower the cost gap between green hydrogen and fossil energy carriers.	Financial support – e.g., financial aid under the Innovation Fund ▪ The European Hydrogen Bank (€3 Bio. volume) is part of the Innovation Fund. It grants a fixed premium payment per kg of produced green hydrogen via supply-side auctions.[2]
Limited infrastructure	Support creation of integrated H_2-eco-systems. Demonstrate proof-of-concept.	Establish hydrogen valleys and match clean hydrogen production with demand within the same geographical area.[3]
Regulatory complexity	Create a clear regulatory environment, speed up hydrogen deployment.	Simplified regulatory framework (NZIA); faster permitting (NZIA); clear definition of green hydrogen (RED II).[4,5]
Import risks	Promote energy security by reducing reliance on a few hydrogen suppliers and ensuring diverse imports.	Apart from measures to scale up European production and trade, Hydrogen Import Partnership Agreements should be established and Hydrogen Bank auctions for non-EU countries are planned.[3,6]

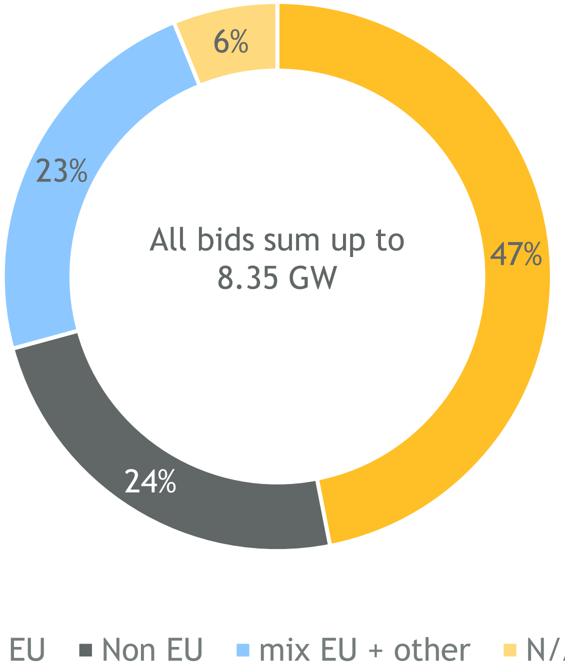
1: European Commission (2022) | 2: European Parliament (2023) | 3: European Commission (2024) | 4: European Hydrogen Observatory (2024) | 5: FfE (2023) | 6: SWP (2023)

3

Electrolyser

There is no established electrolyser market yet. The first auction of the European Hydrogen Bank highlights significant EU sourcing.

Percentage of bids by electrolyser origin in the European hydrogen bank pilot auction[1]



Domestic production and imports today

- To date, international trade in electrolysers has been limited. As of 2023, under 20% of the total 1.4 GW globally installed capacity of water electrolysers has been traded internationally. The first auction for the hydrogen bank also suggests that most bids intend to use electrolysers sourced, at least partially, from within the EU. At present, global manufacturing capacity is well above demand.[1, 2]
- Competition in CCS technology, crucial for producing blue hydrogen, is intensifying, as leadership shifts from North America to Asia.[3] While technological capabilities take priority, critical raw materials are generally not required. However, it is unlikely that Europe will be able to catch up with advances abroad. Complete abandonment could raise dependencies and costs, while ongoing R&D alone may not suffice, making strategic investments and partnerships a potential solution.[4]

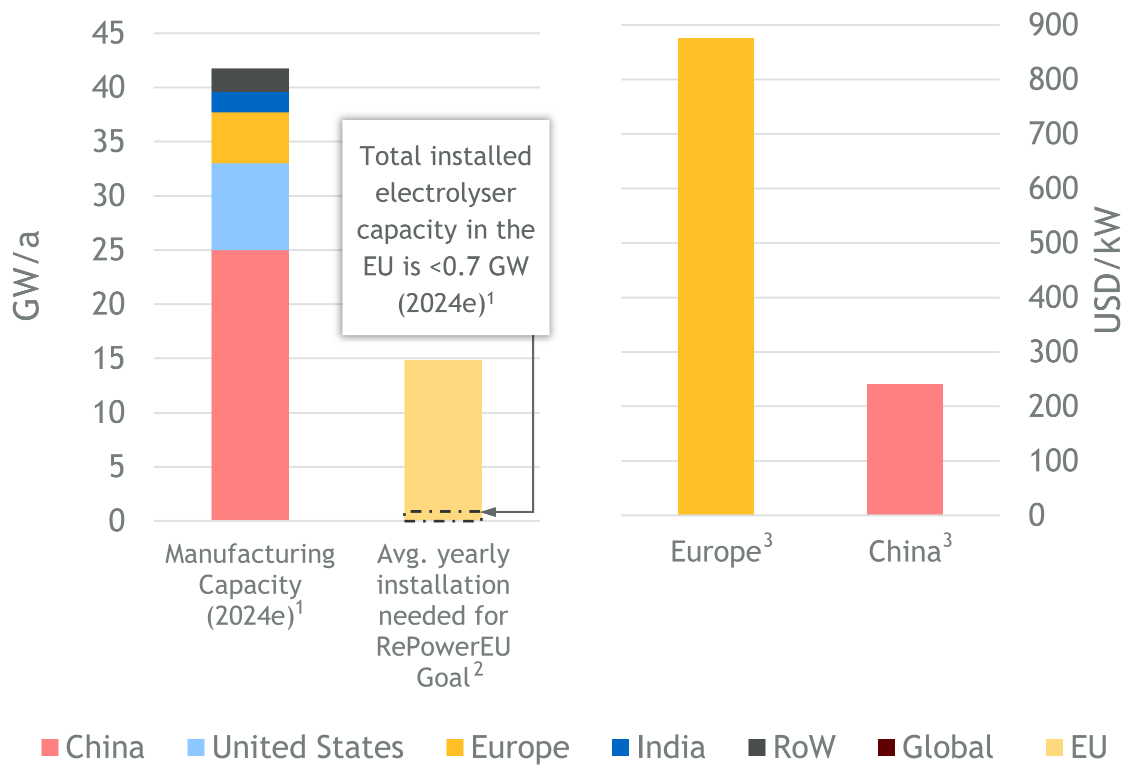
Future production potential

- By 2030, annual production capacity could surpass 165 GW based on all current announcements – nearly 30% of this projected capacity has reached final investment decision (FID), while another 30% has been announced without a confirmed start date.[2]
- China is projected to retain the largest manufacturing share in 2030, with 30%, followed by Europe at 20% and the United States at 15%. Approximately 7% of the announcements – amounting to 12 GW – have been made without a specified location.[2]
- Electrolyser manufacturers mainly operate within their home countries today, although some Chinese companies (e.g. GuofuHee, Trina Hydrogen or Hygreen Energy), are planning to expand into the EU.[2]

1: European Commission (2024) | 2: IEA2024 | 3: European Parliament (2021) | 4: SWP (2024)

A growing market for electrolysers could open export potential for European companies, despite current cost disadvantage

Electrolyser manufacturing capacity, needed installation rate for RePowerEU Goals and Alkaline Electrolyser Price by region.



- **Market growth:** The global market size for electrolysers is estimated to reach roughly 50 Bio. Euro by 2030 although hydrogen ramp-up is lagging targets in many areas of the world.[1, 4, 5]
- **Competition:** In 2023, the electrolyser market share by region was led by Asia Pacific at 45.6%, followed by Europe at 26.5%, North America at 19.0%, and LAMEA (Latin America, Middle East, and Africa) at 8.9%.[6] Manufacturing capacity exceeds yearly demand significantly, potentially leading to competition as demand grows in the future.[1]
- **Profitability:** Estimated European electrolyser prices exceed those of their Chinese counterparts by 360 %, limiting profitability in a growing market.[3] Future decreases in costs and hence prices, e.g., due to automated stack production, can decrease this difference to an unknown extent. In addition, differences in quality can increase support the share of European companies despite cost disadvantages.[7,8]
- **Market maturity and risk:** Apart from alkaline electrolysis („Early Adoption“), PEM and SOE are still in the phase „Prototype and Demonstration“, hence some market risk remains. [9]

1: IEA (2024) | 2: Assumption: If a total of 90 GW of installed electrolyser capacity is needed by 2030 (see European Commission (2022)), and an anticipated capacity of 0.7 GW reached by the end of 2024 (see IEA (2024)), it will be necessary to achieve an average annual capacity addition of approximately 15 GW from 2025 to 2030. | 3: pvmagazine (2024), price comparison for Alkaline Electrolyser (AEM), Proton Exchange Membrane Electrolyser (PEM) prices currently higher | 4: BDI, BCG, IW (2024) | 5: Hydrogen Council (2024) | 6: Precedence Research (2024) | 7: IRENA (2020) | 8: Hydrogen Insight (2023) | 9: Li et al. (2024)

Achieving scale effects and technological advancement by triggering investments.

NZIA Objective: "The Act sets a goal for net-zero manufacturing capacity to meet at least 40% of the EU's annual deployment needs by 2030, providing predictability, certainty and long-term signals to manufacturers and investors."[1]

Obstacle	Policy Goal	Selected Policy Instruments
High production costs	Lower production costs and scale up electrolyser production. Facilitate market competitiveness.	Access to finance, such as: • **EU Innovation Fund:** Supports the demonstration of low-carbon technologies with grants and auctions (overall volume of around €40 Bio.).[2] • **IPCEI:** For example, Hy2Tech included funding for developing, testing, and validating electrolysers and components (overall €5.4 Bio. public funding).[3]
Project complexity	Streamline project approval for faster implementation and ensures skilled labor.	**NZIA** establishes deadlines for permit-granting processes and supports skill development via Net-Zero Industry Academies.[4]
Technological risk	Encourage innovation, reduce technological uncertainties, and accelerate R&D.	**Horizon Europe** (€1 Bio.) is a funding program focusing on research and innovation (overall volume of €93.5 Bio. for the period 2021-2027).[5]
Import risks	Enhance supply chain resilience and mitigate dependency on external imports.	**Hydrogen bank:** Plans on enforcing a 25% limit on key electrolyser manufacturing steps taking place in China and in the next auction.[6] **NZIA:** Building industrial partnerships to diversify trade and investments.[4]

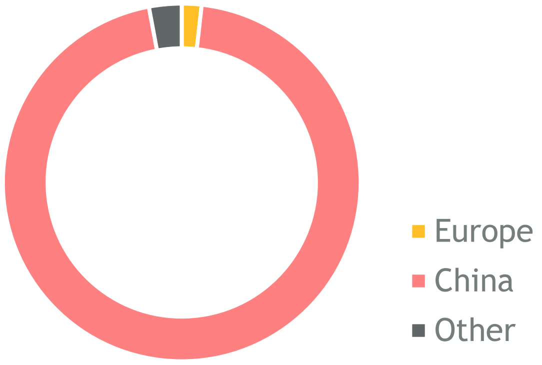
1 European Parliament (2024) | 2: European Commission (2023) | 3: European Commission (2022) | 4: European Commission (2023) | 5: European Commission (2023) | 6: European Commission (2024)

4

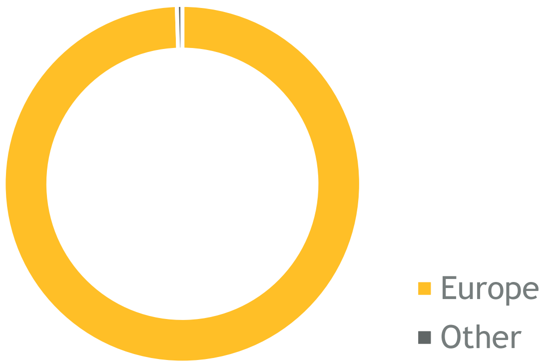
Electricity Generation

Europe's high dependence on solar imports will likely persist. Its wind energy value chain is robust, but its future is uncertain.

Import Dependence - Solar panels[1,2,a] (2023)



Import Dependence - Wind Turbines[1,3,b] (2023)



Domestic production and imports today

- Europe is highly dependent on the import of solar panels from China, which supplies around 98% of imports.[1] In 2023, the EU installed 56 GW of solar capacity, yet its capacity for key manufacturing steps —like ingot and wafer production— is under 0.3 GW. While Norway and Switzerland add another 1 GW for these stages, the EU/ Europe remains highly dependent on imports from China.[2]
- Wind technology suppliers currently prefer manufacturing close to demand to avoid high costs and risks of transporting large, fragile components. Manufacturing capacity for key components (nacelle, blade, tower, foundation) currently (almost) meets demand in the EU.[3,4]

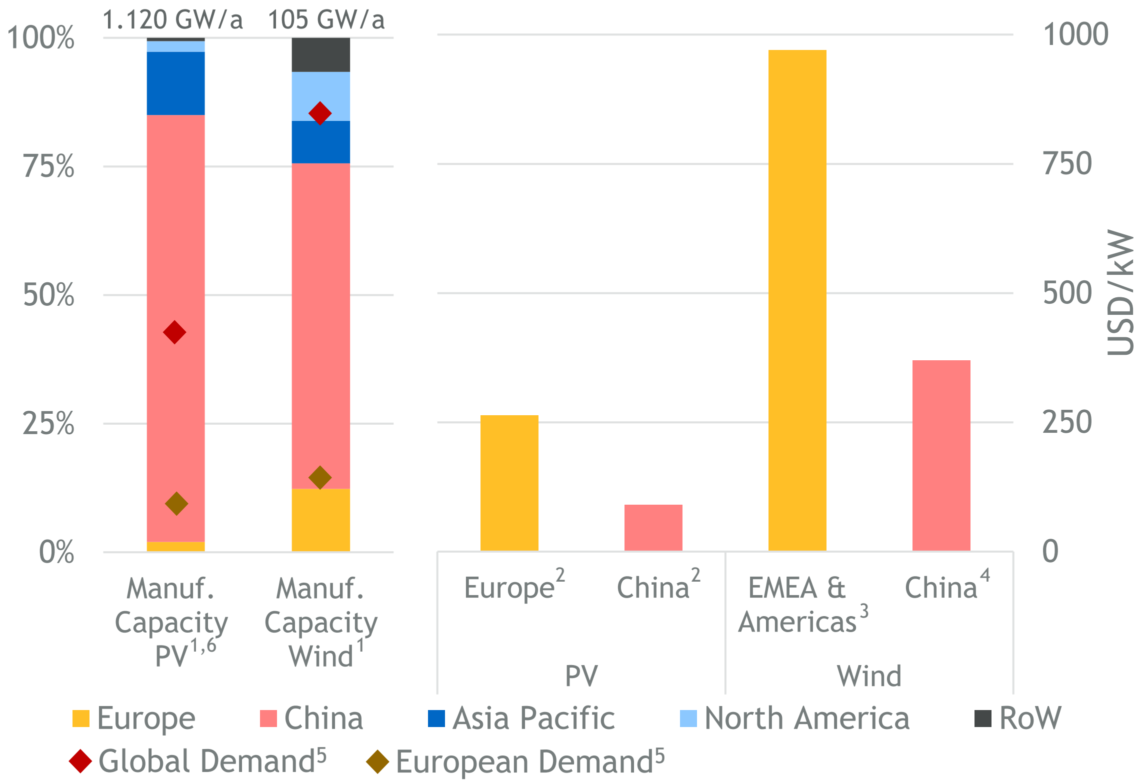
Future production potential

- Since 2023, several stages of solar manufacturing have seen capacity expansions in the EU. However, ingot and wafer production remain the steps in the supply chain with the least manufacturing capacity. Without additional policy measures, progress toward supply chain independence is unlikely.[4, 5]
- By 2025, Europe is expected to be able to meet its demand for offshore components domestically (except for blades with a shortfall of around 1 GW with overall 6 GW demand). For onshore, only blade demand may be fully met. Expected shortfalls are up to 4 GW, with 17 GW demand anticipated.[4]
- Although main Chinese manufacturers currently hold under 1% of Europe's wind capacity they are starting to secure European orders, with volumes of 1.2 GW in 2023 alone.[6,c] However, this does not necessarily imply less production for European companies in a growing market.

a: European share assumes that the entire value chain is localized within Europe (1 GW bottleneck production capacity). The remaining demand is split between Chinese imports (98%) and Others (2%) | b: Minor dependencies remain. On- and offshore technologies are not distinguished. | c: Goldwind, Mingyang Smart Energy, and Windey | 1: eurostat (2024) | 2: SolarPower Europe (2023) | 3: Rystad Energy (2023) | 4: IEA (2023) | 5: ESIA (2024) | 6: Reuters (2024)

Growing Solar and Wind Markets are Under Pressure: European Manufacturers Challenged by China's high Capacity and Low Prices

PV and Wind technology manufacturing capacity, solar production cost and wind turbine price by region in 2024.



- **Market growth:** Global market size for solar PV is expected to increase from around 1,700 GW in 2024 to more than 6,000 GW in 2030. Wind power capacity is projected to rise from around 1,150 GW in 2024 to almost 2,900 GW in 2030 (both: NZE Scenario).[7,12]
- **Competition:** Based on international shipments of PV-modules, China makes up around 63%, APAC 34% and North America 2% of international trade. Europe's role is negligible.[8] Chinese suppliers dominate in technology, quality, and pricing, forcing European companies (re-)entering PV ingot/ wafer manufacturing to not only upgrade their technology but also match the low prices to compete.[9] Wind technology components are harder to transport, leading to more dispersed manufacturing. In terms of global market share by take-in orders, Chinese firms held about 66%, European firms 17%, and U.S. companies around 5% in 2022.[10]
- **Profitability:** European PV firms face challenges from Asia, whose strength stems from learning effects and economies of scale, making subsidies essential. Although wind tech manufacturing is less impacted, rising raw material costs are pressuring European manufacturers' margins.[11]
- **Market maturity and risk:** The solar PV and wind energy markets are, in principle, well-established. However, as demand grows for increasingly larger systems, innovation is needed, and technological risks arise.[13]

1: IEA (2023), Manufacturing capacity for PV refers to solar modules and for wind to onshore wind nacelle, linear interpolation between 2022 and 2025 | 2: PV magazine (2024), avg. module price made in China and Europe | 3: Vestas (2024), Vestas' avg. selling price as a proxy for EMEA and Americas – prices may differ between regions (order volume: 45% EMEA, 50% Americas) | 4: BNEF (2024), Avg. turbine bids in China. | 5: Demand as percentage of global manufacturing capacity. | 6: IEA (2024) | 7: IEA (2023) | 8: IEA (2021) | 9: SolarAlliance (2024) | 10: Enerdata (2024) | 11: Fitch Ratings (2023) | 12: IEA (2023) | 13: Fraunhofer (2021)

Reducing energy dependence by addressing manufacturing bottlenecks and keeping diversifying imports.

NZIA Objective: By 2030, target manufacturing capacities of 30 GW for solar PV and 36 GW for wind energy across the entire value chain.[1]

Obstacle	Policy Goal	Selected Policy Instruments
High production costs	▪ Incentivize solar PV and wind technology manufactures to (re-)enter and expand production capacities. ▪ Facilitate lower production costs and scaling up of production capacities. ▪ Facilitate market competitiveness.	Access to finance, such as: ▪ The **EU Innovation Fund** (e.g., in 2024, 6 grants supported wind turbine factories, and in 2023, 6 grants went to solar manufacturing projects.).[2,3] ▪ the **European Investment Bank** (borrows to clients on favorable conditions; e.g., over the last 10 years €2 Bio. for solar PV industry – manufacturing and innovation)[3] or ▪ **Horizon Europe** (funding for research and innovation, around €220 Mio. for PV research innovation between 2021 and 2024).[3]
Project complexity	▪ Streamline project approval for faster implementation and ensures skilled labor.	The **NZIA** establishes **deadlines for permit-granting** processes for net-zero manufacturing projects and aims at supporting **skill development** in the sector (same as for electrolysers).[4]
Import risks	▪ Enhance supply chain resilience and mitigate dependency on external imports.	Under the **NZIA**, annual reports are planned to monitor the diversification of net-zero technologies. Though incentive mechanisms are still undefined, these diversification indicators should guide the development programs that incentivize purchasing net-zero technology products.[1,a]

a: A net-zero technology is insufficiently diversified if over 50% is supplied by one country. | 1: European Parliament (2024) | 2: European Commission (2024) | 3: Solar Power Europe (2024) | 4: European Commission (2023)

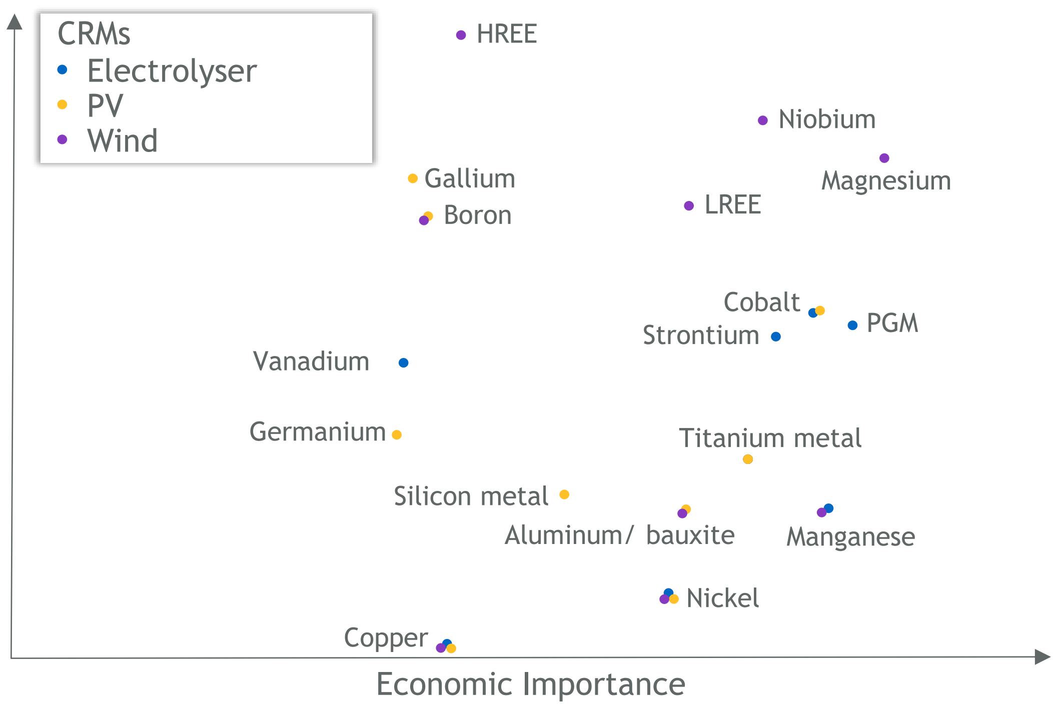
5

Raw Materials

The production of electrolysers as well as RE resources requires a wide range of (Critical) Raw Materials

- Global pressure on resources is set to increase significantly, with the transition to climate neutrality being a main driver. The OECD predicts that global material consumption will more than double, from 79 Bio. tons today to 167 Bio. tons by 2060, intensifying global competition.
- To avoid excessive dependencies, diversification of supply is key. This involves sourcing primary raw materials from both the EU and third countries, boosting secondary supplies through circularity and efficiency, and identifying alternatives to scarce materials.
- Critical Raw Materials (CRMs) are defined in response to the growing concern within the EU and globally over ensuring reliable and unhindered access to certain raw materials. They are defined as materials vital to the EU's economy but with high supply risks. Criticality is determined by two factors: Economic Importance (EI) and Supply Risk (SR).
  - Supply Risk is assessed based on factors that evaluate the likelihood of disruptions in the supply of a specific material, such as global production, the mix of EU sourcing countries, and import dependency.
  - Economic Importance is determined by the significance of a material for end-use applications within the EU and the effectiveness of available substitutes for those applications.[1]

Results of the 2023 EU criticality assessment[1,a]

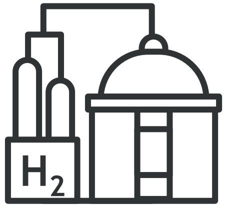


1: European Commission (2023) | a: Selection of materials based on Eikeng et. al (2024) and European Commission (2020)

Imports of raw materials for electrolyser production are highly dependent on a few countries

Main Critical Raw Materials[1]	Stage[2]	EU Import Reliance[3]	Main EU sourcing countries[4]	EoL-RIR[5]
Cobalt	P	81%	Congo, D.R. (69%), Russia (6%), Australia (5%)*	22%
Nickel	R	75%	Russia (29%), Finland (17%), Norway (10%)	16%
PGMs				
Iridium	P	100%	South Africa (>90%)	14%*
Ruthenium	P	100%	South Africa (>90%)	14%*
Platinum	P	94%	South Africa (68%), Russia (13%)	11%
Palladium	P	98%	Russia (41%), S. Africa (33%)	10%

Status-Quo: Raw materials for electrolyser production



- Electrolyser production depends heavily on strategic raw materials, which may become a bottleneck scaling up the hydrogen economy.
- PEM electrolysers, which are suitable for volatile hydrogen production via RE, depend strongly on PGMs. As EoL-recycling amounts to only 10% and own reserves are negligible, the EU relies heavily on imports.
- Additionally, the EU shows a high reliance on imports of primary Cobalt. The EU holds 5.7% of global reserves and makes up around 0.8% of primary (IR = 81% [3]) and 9.7% of refined (IR = 1% [3]) production worldwide.[7]

Future Potential (PGMs)

- **Extraction:** The EU holds around 0.4% of global PGM deposits and accounts for 0.5% or primary production [6]. Most notably are reserves in Finland. However, most mines remain unexploited [7].
- **Diversification:** The potential for diversification is limited as global supply of primary PGMs is concentrated in South Africa and Russia. Diversification may be feasible through existing producers, like Zimbabwe or the USA [6].
- **Recycling:** PGMs are estimated to have a technical recyclability of up to 95%, highlighting untapped potential. Key opportunities are expected in improving end-of-life collection of PGM-containing equipment[8]. EU funded projects like PLATIRUS aim at addressing the supply gap through research, lab validation, industrial testing, and market preparation[10].

1: Data based on: European Commission (2023), European Commission (2023), SCRREEN (2023); Selection of materials based on Eikeng et. al (2024) - CRMs needed for PEM and AEL; characteristics of manganese and aluminum provided on following slides | 2: P = Primary, R = Refined| 3: EU import reliance = (Import - Export) / (Domestic production + Import - Export); without recycling | 4: Based on domestic production and import (export excluded) | 5: The EoL-RIR (End of Life Recycling Input Rate is the percentage of overall demand that can be met through secondary raw materials | 6: European Commission (2023) |7: Eilu et al. (2021) | 8: IPA (2022) | 9: Platirus (2021) | * global figure (no data available for EU)

The production of PV modules relies on critical raw materials and exhibits strong dependencies on each stage of the value chain.

Main Critical Raw Materials[1]	Stage[2]	EU Import Reliance[3]	Main EU sourcing countries[4]	EoL-RIR[5]
Aluminum	P	89%	Guinea (62%), Brazil (12%), Greece (10%)	21%
Boron	E	100%	Türkiye (99%)	1%
Copper	E	48%	Poland (19%), Chile (14%), Peru (10%)	55%
Gallium	P	98%	China (69%), USA (10%), United Kingdom (9%)	0%
Germanium	P	42%	China (45%), Belgium (32%), Germany (19%)	2%
Silicon metal	P	46%	Norway (34%), France (29%), Brazil (9%)	0%

Status-Quo: Raw materials for solar PV production

- The EU27 supplies about 6% of the required raw materials, with an additional 3% coming from the rest of Europe. In contrast, China accounts for 53%, underscoring a substantial supply dependence. A similar pattern exists for processed materials, where the EU27 provides 5% and China dominates with 50% of the supply.[6]
- However, component production and assembly are heavily concentrated in China, accounting for 89% and 70% of global supply, making the later stages of the supply chain particularly critical. Moving the value chain to Europe could reduce dependence but may face challenges with Aluminum, Boron, and Gallium due to low diversification and high import reliance .[6,7]

Future Potential (Boron, Gallium)

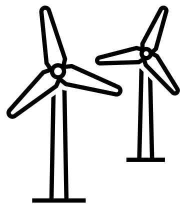
- **Extraction:** The EU has no known Boron reserves or processing facilities. Gallium reserves are uncertain and uneconomic under current market conditions. Most processing has ceased due to low profitability.[8,9]
- **Diversification:** Boron supply may be diversified as the US is also a major exporter, with Chile or Russia also contributing. Global supply of processed Gallium, however, stems mainly from China (95%) and Russia (3%).[7]
- **Recycling:** Recycling rates are low due to high costs, with boron non-functionally recyclable and gallium difficult to recover due to its dispersion. Recycling will likely remain challenging due to competition with market prices.[8,9]

1: Data based on European Commission (2023), European Commission (2023); Selection of materials based on European Commission (2020); characteristics of Molybdenum, Nickel and Zinc are provided on the previous and the following slides | 2: P = Primary, R = Refined | 3: EU import reliance = (Import - Export) / (Domestic production + Import - Export); without recycling | 4: Based on domestic production and import (export excluded) | 5: The EoL-RIR (End of Life Recycling Input Rate) is the percentage of overall demand that can be met through secondary raw materials | 6: European Commission (2020) |7: European Commission (2023) | 8: SCRREEN (2023) | 9: SCRREEN (2023) | * global figure (no data available for EU)

The production of wind turbines relies on critical raw materials and shows dependencies at the beginning of the value chain.

Main Critical Raw Materials[1]	Stage[2]	EU Import Reliance[3]	Main EU sourcing countries[4]	EoL-RIR[5]
Manganese	P	96%	South Africa (41%), Gabon (39%), Brazil (8%)	9%
Niobium	R	100%	Brazil (82%), Canada (16%), UK (2%)	0%
HREE[6]				
Dysprosium	R	100%	China (100%)	0%
LREE[6]				
Neodymium	R	100%	China (85%)	1%
Praseodymium	R	100%	China (85%)	1%

Status-Quo: Raw materials for wind energy production



- The EU27 and the rest of Europe supply only around 1% of raw materials for wind turbines, while China and Latin America provide around 54% and 29%, respectively. As the EU has considerable capacities in the remaining steps of the value chain, raw material supply is considered a bottleneck.[7]
- Regarding the individual raw materials needed, particularly heavy and light rare earth elements (HREE, LREE) are considered critical materials which may become limiting factors in the expansion of wind energy. [7]

Future Potential (HREE, LREE)

- **Extraction:** Sweden and Greenland show some potential for REE exploitation but face challenges from low market conditions and environmental concerns. Global mine production is dominated by China (62%), followed by the USA (17%), Myanmar (9%), and Australia (9%).[8]
- **Diversification:** Diversifying REE supply is difficult as 85% of refined REEs are produced in China, benefiting from high efficiency and low transport costs, which limit global competition.[8]
- **Recycling:** Today, recycling input rates are extremely low, due to inefficient collection systems and high recycling costs in Europe. Permanent magnets are expected to become key secondary resources for recovering neodymium, praseodymium, and dysprosium. While recycling capacity is expected to grow, targets are unlikely to be met.[8,9]

1: Data based on: European Commission (2023), European Commission (2023), SCRREEN (2023) ; Selection of materials based on European Commission (2020); characteristics of Copper, Nickel, Aluminum and Boron are provided on the previous slides | 2: P = Primary, R = Refined| 3: EU import reliance = (Import - Export) / (Domestic production + Import - Export)); without recycling | 4: Based on domestic production and import (export excluded) | 5: The EoL-RIR (End of Life Recycling Input Rate is the percentage of overall demand that can be met through secondary raw materials | 6: HREE and LREE = heavy and light rare earth elements | 7: European Commission (2020) | 8: SCRREEN (2023) | 9: Reuters (2024)

The EU addresses its import dependence through the Critical Raw Materials Act, which formulates specific targets and approaches.

CRMA Objective: Establish benchmarks for the EU's domestic raw material capacities: at least 10% of annual consumption for extraction, 40% for processing, and 25% for recycling, as well as no more than 65% import reliance on a single third country.[1]

Obstacle	Policy Goal	Selected Policy Instruments
Necessity of uniform understanding and collaboration	▪ Ensure consistent definitions and monitoring of CRMs and SRMs, including assessment of their economic importance and supply risks. ▪ Identify and prioritize areas requiring action.	**Raw Materials Initiative** (2008)[2] and extension through **CRMA** (2024)[1] aim at establishing a uniform catalogue and methodology for CRM/SRM-assessment ▪ Publication of Critical and Strategic Raw Materials lists at least every 3 years to reflect production, market and technological developments. ▪ Economic Importance (EI) and Supply Risk (SR) factors to assess criticality
Limited R&D and fragmented collaboration	▪ Boost raw materials research and sustainability. ▪ Foster collaboration across industry, academia, and civil society. ▪ Definition and support of "strategic projects"	▪ Funding via **Horizon Europe** (e.g., Horizon Resilient Value Chains 2024[3]) ▪ Priority treatment of **strategic projects** targeting supply of CRMs or SRMs[1] ▪ **European Innovation Partnership** on Raw Materials for stakeholder collaboration[3] ▪ **European Raw Materials Alliance** to support raw materials ecosystem[4]
Import risks	▪ Strengthen supply chain resilience and reduce dependency. ▪ Secure upstream resources and prepare for disruptions.	The **CRMA** ▪ allows for strategic stockpiling, ▪ envisions a Critical Raw Materials Club for global partnerships, and ▪ enables using Global Gateway initiative for upstream investments abroad[6]

1: European Parliament (2024) | 2: European Parliament (2008) | 3: European Commission (2024) | 4: IEA (2022) | 5: ERMA (2024) | 6: Carnegie Europe (2024)

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