Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis

Final report

Written by Trinomics and Artelys
June – 2021

Authors:

Frank Gérard	(Trinomics)
João Gorenstein Dedecca	(Trinomics)
Ling Ying Lee	(Trinomics)
Liliana Guevara Opinska	(Trinomics)
Jessica Yearwood	(Trinomics)
Onne Hoogland	(Trinomics)
Christopher Andrey	(Artelys)

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Directorate B — Just Transition, Consumers, Energy Efficiency and Innovation
Unit B4 — Energy Security and Safety

Contact: Rémi Mayet, Mugurel-George Păunescu

E-mail: remi.mayet@ec.europa.eu, mugurel-george.paunescu@ec.europa.eu

European Commission
B-1049 Brussels

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Contents

List of acronyms

APCRM	Action Plan on Critical Raw Materials
BACS	Building automation and control systems
BECCS	Bio-energy carbon capture and storage
BEMS	Building energy management systems
CCGT	Combined-cycle gas turbine
CCU/S	Carbon capture, utilisation and storage
CEAP	Circular Economy Action Plan
CETA	Comprehensive Economic & Trade Agreement
CET TIR	Clean Energy Transition – Technologies and Innovations Report
CGD	Commercial-grade dedication
CER Directive	Critical Entities Resilience Directive
CFC	Carbon Fibre Composites
CHP	Combined heat and power
CRM	Critical raw material
DER	Distributed energy resources
DHC	District heating and cooling
EEA	European economic area
ERMA	European Raw Materials Alliance
GHG	Greenhouse gas
GOES	Grain-oriented electrical steel
HEMS	Home energy management systems
HFC	Hydrogen fuel cell
HRS	Hydrogen refuelling station
HVAC	Heating, ventilation and air conditioning
HVDC	High-voltage direct current
ICT	Information and communication technology
IGCC	Integrated gasification combined cycle
IoT	Internet of Things
ISO	International Organisation for Standardization
IT	Information technology
LIB	Lithium-ion battery
LNG	Liquefied natural gas
LTS	Long-term Strategy
NIS Directive	Directive on Security of Network and Information Systems
NPP	Nuclear power plant
OCGT	Open-cycle gas turbine
OT	Operational technology
PCB	Printed Circuit Board
PEMFC	Proton-exchange membrane fuel cell
PFSA	Perfluoro-sulfonated acids
PGM	Platinum group metals
PHS	Pumped hydropower storage
PPE	Personal protection equipment
RCF	Recycled carbon fuels
RFNBO	Renewable fuels of non-biological origin
RMIS	Raw Materials Information System
SCADA	Supervisory control and datal acquisition
SET	Strategic Energy Technologies
SMR	Steam methane reforming
Solar PV	Solar photovoltaics
SoS	Security of supply
V2G	Vehicle-to-grid
XLPE	Cross-linked polyethylene
WTIV	Wind turbine installation vessel
WTO	World Trade Organisation

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The authors thank all stakeholders which have strongly supported the analysis of the specific supply chains and the overall study, and FastMarkets for providing price data for raw materials.

List of abbreviations of chemical elements

Abbreviation	Element
Ac	Actinium
Al	Aluminum
Am	Americium
Sb	Antimony
Ar	Argon
As	Arsenic
At	Astatine
Ba	Barium
Bk	Berkelium
Be	Beryllium
Bi	Bismuth
Bh	Bohrium
B	Boron
Br	Bromine
Cd	Cadmium
Ca	Calcium
Cf	Californium
C	Carbon
Ce	Cerium
Cs	Cesium
Cl	Chlorine
Cr	Chromium
Co	Cobalt
Cn	Copernicium
Cu	Copper
Cm	Curium
Ds	Darmstadtium
Db	Dubnium
Dy	Dysprosium
Es	Einsteinium
Er	Erbium
Eu	Europium
Fm	Fermium
Fl	Flerovium
F	Fluorine
Fr	Francium
Gd	Gadolinium
Ga	Gallium
Ge	Germanium
Au	Gold
Hf	Hafnium
Hs	Hassium
He	Helium
Ho	Holmium
H	Hydrogen
In	Indium
I	Iodine
Ir	Iridium
Fe	Iron
Kr	Krypton
La	Lanthanum
Lr	Lawrencium
Pb	Lead
Li	Lithium
Lv	Livermorium
Lu	Lutetium
Mg	Magnesium
Mc	Moscovium
Mn	Manganese
Mt	Meitnerium

Abbreviation	Element
Md	Mendelevium
Hg	Mercury
Mo	Molybdenum
Ns	Neilsborium
Nd	Neodymium
Ne	Neon
Np	Neptunium
Nh	Nihonium
Ni	Nickel
Nb	Niobium
N	Nitrogen
No	Nobelium
Og	Oganesson
Os	Osmium
O	Oxygen
Pd	Palladium
P	Phosphorus
Pt	Platinum
Pu	Plutonium
Po	Polonium
K	Potassium
Pr	Praseodymium
Pm	Promethium
Pa	Protactinium
Ra	Radium
Rn	Radon
Re	Rhenium
Rh	Rhodium
Rg	Roentgenium
Rb	Rubidium
Ru	Ruthenium
Rf	Rutherfordium
Sm	Samarium
Sc	Scandium
Sg	Seaborgium
Se	Selenium
Si	Silicon
Ag	Silver
Na	Sodium
Sr	Strontium
S	Sulfur
Ta	Tantalum
Tc	Technetium
Te	Tellurium
Ts	Tennessine
Tb	Terbium
Tl	Thallium
Th	Thorium
Tm	Thulium
Sn	Tin
Ti	Titanium
W	Tungsten
U	Uranium
V	Vanadium
Xe	Xenon
Yb	Ytterbium
Y	Yttrium
Zn	Zinc
Zr	Zirconium

EXECUTIVE SUMMARY

The objectives of this study are to:

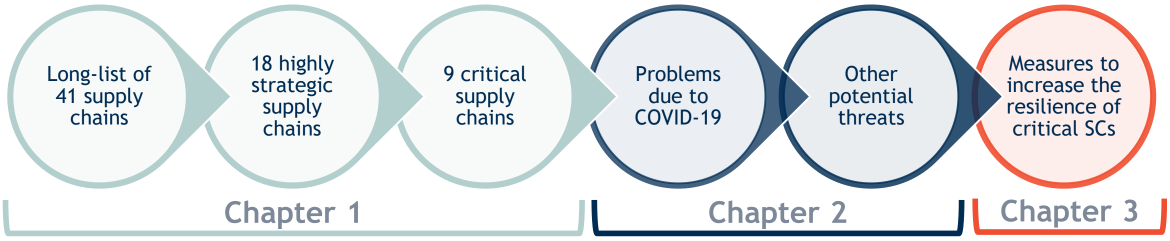
1. Identify the energy technology supply chains that are critical for a) ensuring the EU security of energy supply and b) achieving the EU clean energy transition, taking into account the current vulnerabilities of these supply chains against several threat scenarios; and
2. Identify measures to strengthen the resilience of the critical energy technology supply chains and of the European energy sector more broadly.

We define **critical energy technology supply chains** as those with a:

- **High strategic importance to the EU** clean energy transition and/or to guarantee the security of energy supply; and a
- **High vulnerability**, regarding the entire supply chain, or specific stages (such as manufacturing) or elements (e.g. a specific raw material, a manufactured component, or a certain expertise for O&M).

In **chapter 1**, a long-list of 41 energy technology supply chains is identified. From this list, 18 highly strategic supply are identified. Of these, 9 are determined as critical due to their vulnerabilities. This process is illustrated in the figure below, and the full list of supply chains presented in the next page. **Chapter 2** then assesses the problems which may arise from threat scenarios (persistent pandemics, extreme weather events, cyber threats and geo-political tension). Finally, **chapter 3** develops measures to increase the resilience of these supply chains to the considered threat scenarios.

Figure 0-1 Process to identify critical supply chains, assess problems due to COVID-19 and other threats, and develop policy measures



This study is based on data from publicly available documents as well as inputs received from stakeholders through the organisation of an online survey, via interviews and feedback they have provided to written material. The level of detail provided for certain supply chains is thus constrained by the available information. Therefore, the study also helps pinpointing vulnerable elements of critical energy technology supply chains for which little knowledge is available. Moreover, this study focuses on a number of supply chains considered most critical due to the need to concentrate the available study resources. This does not mean other energy technologies are not important to the EU energy system nor that their supply chains do not exhibit vulnerabilities.

The insights of this study could also be complemented by other recent works regarding the resilience of the energy system for the global progress towards a low carbon economy. As example, the World Energy Outlook special report on "The Role of Critical Minerals in Clean Energy Transitions" (IEA, 2021[1]) provides a global perspective and identifies global challenges for the sustainable and secure supply of minerals. The IEA report identifies risks to key minerals and metals considered critical for the global energy transition, and that could therefore hamper international efforts to tackle climate change.

Chapter 1: Identification of the critical supply chains for the energy sector

Chapter 1 first defines a list of strategic energy technology supply chains (section 1.1) and then conducts an assessment of the vulnerability of strategic supply chains in order to define the list of critical supply chains (section 1.2).

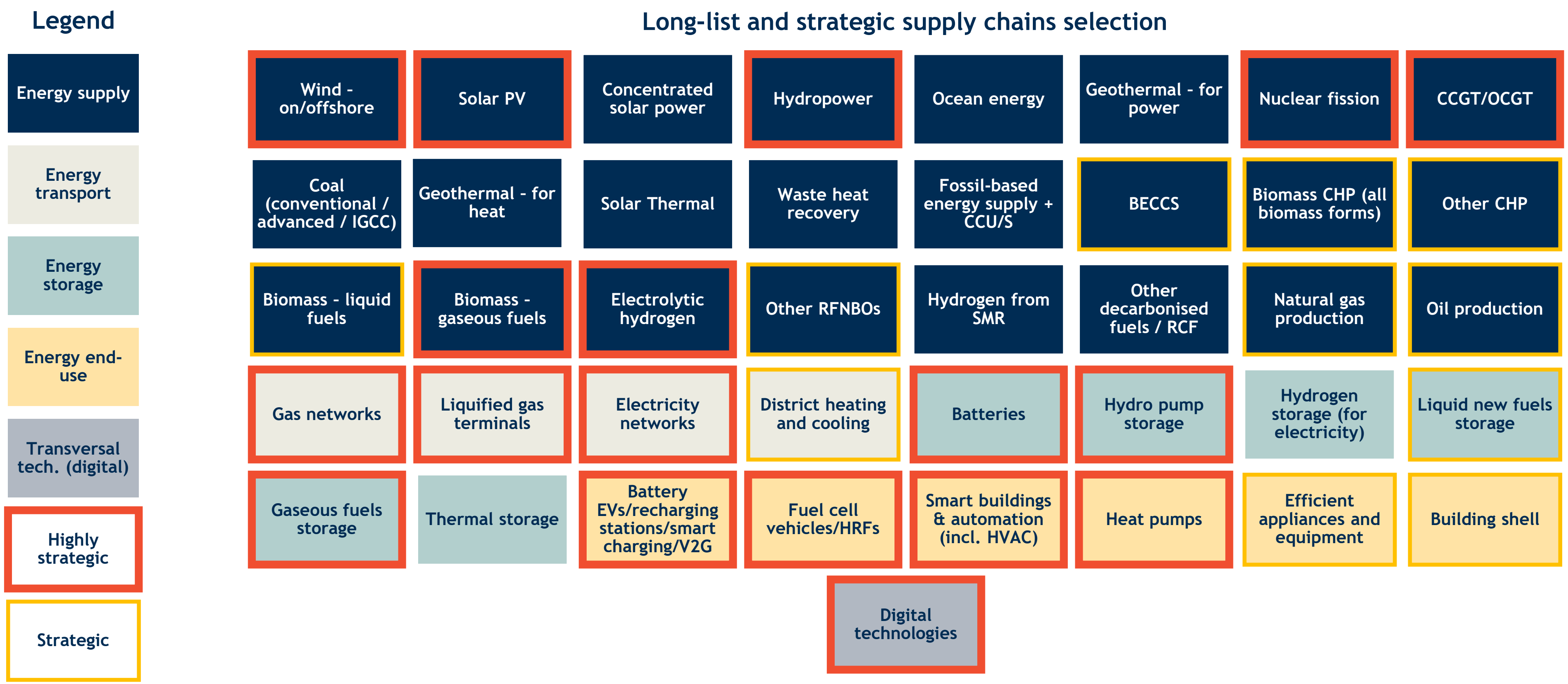
Section 1.1: Identification of strategic energy technology supply chains

In section 1.1, the study identifies highly strategic energy technology supply chains for the European energy sector based on their contribution to the EU security of energy supply (in the short- and long-

[1] IEA. (2021). The role of critical minerals in clean energy transitions – part of World Energy Outlook. Available at: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

term) and to the clean energy transition (in the long-term). Four indicators are used to identify the highly strategic energy technology supply chains from a long-list of technologies. The indicators employed are the current share of energy supply/transmission/storage/use, the long-term share of energy supply/transmission/storage/use, the ability to provide flexibility services to the energy system, and additional qualitative aspects including policy priorities. The main source was the 1.5TECH scenario of the European Commission's Long-Term Strategy, complemented by other sources. As a result, **the study identifies 18 highly strategic supply chains across the EU energy sector**, as shown in the figure below.

Figure 0-2 Overview of strategic energy technology supply chains and other supply chains considered



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In addition, other energy technology supply chains such as for liquid biofuels or carbon capture and storage may also be very strategic to certain sub-sectors (e.g. for decarbonising heavy duty freight or aviation in the case of biofuels) but were not included in the list of critical supply chains as they impact specific sub-sectors rather than the broader EU energy system, and due to the need to keep the list to a manageable number of supply chains.

Section 1.2: Assessment of vulnerabilities and definition of critical supply chains

In section 1.2, the study zooms-in on the highly strategic supply chains to identify key vulnerabilities per each supply chain stage (from raw material sourcing to manufacturing, operation and maintenance, and decommissioning).

The high-level assessment of vulnerabilities per element in the supply chains is based on criteria covering the EU import dependency, market concentration, extent of know-how and specialisation in Europe, ease of substitutability and price stability. In addition, information obtained from stakeholder consultation and interviews is incorporated in the analysis.

Based on the high-level assessment of vulnerabilities, 9 supply chains are considered to have important vulnerabilities. The critical energy supply chains identified are: wind energy (onshore and offshore), solar PV, nuclear fission, hydrogen production, storage & use technologies, gas infrastructure, electricity networks, batteries, smart buildings and building automation, and digital technologies in the energy sector. The figure below indicates the specific elements and supply chain stages which are considered to be vulnerable. **Hydropower and pumped storage, biomass gasifiers, gas turbines and heat pumps are considered highly strategic but no significant vulnerabilities were identified** compared to the supply chains above. Hence they are not considered critical, despite their strategic importance to the EU energy system and their potential contributions to its resilience.

Table 0-1 Overview of the vulnerability of energy technologies supply chain stages

Strategic supply chains	Raw & Processed Materials	Manufacturing & Assembly	O&M
Wind	Cu, **Dy**, **Nd**; electrical steel	Permanent magnets	Vulnerability to cyber attacks due to increased digitalisation Availability of installation vessels for offshore wind
Solar PV	**B,** Cu, **Ga**, **Ge**, **In**, Se, **Si**, Te	PV cells and modules	Potential for vulnerability to cyber attacks due to remotely controlled inverters
Nuclear fission	Ar, Cr, N, Zn; Ni-Cr-Fe alloys	Nuclear-grade certified suppliers (primary circuits, rods and other components/services for the nuclear island)	Certified service providers
H_2 production / storage / use	**PGMs (Pt, Pd, Ru, Rh, Ir), REEs , Ti** CFC, (PFSA)	(HFC stack assembly, with decreasing vulnerability)	
Gas infrastructure		Ball valves, filters, and purifiers	Cyber security of control systems / 3rd party service providers
Electricity networks	Al**,** Cu, **Mg**, **Si**; electrical steel		Cyber security of control systems / 3rd party service providers
Batteries	Al**, Co, Li, Nb,** Ni, **Si**, **Ti, graphite**	Li-ion cells, cathode, anode, electrolyte, separator	
Smart buildings	**B, Co, Ga, Ge, In, Li, Mg, graphite, PGMs, REEs, Si, W**	Home energy management systems	Cyber security of home/building energy management systems and decentralised devices
Digital technologies	**B, Co, Ga, Ge, In, Li, Mg, graphite, PGMS, REEs, Si, W**	Electronic boards, semiconductors and processors Servers and data storage equipment	Related to cyber-security of digital technologies use in other supply chains

Legend:
orange – supply chain stage with a few vulnerable elements / with high risk vulnerabilities;
yellow - supply chain stage with one to a couple of elements identified as vulnerable;
green – supply chain stage without vulnerable elements;
bold *– critical raw materials (CRMs) based on EC list for 2020.*

Generally, the raw and processed material stage of the supply chains is the most vulnerable stage for many supply chains. More than half of the raw materials defined as critical in the EU Critical Raw Materials List for 2020 play an important role in the supply chains analysed. **Manufacturing & assembly is the second most vulnerable stage across technologies**. While EU companies are important global players in certain supply chains, the EU is highly dependent on imports of multiple or a few critical elements for other supply chains including solar panels, lithium-ion batteries, printed circuit boards, semiconductors, and nuclear-grade elements for nuclear power plants. The O&M stage exhibits vulnerabilities for several technologies (wind, nuclear fission, electricity networks, gas infrastructures and digital technologies) related especially to cyber-security concerns.

Chapter 2: Assessment of current and potential problems for critical supply chains

Chapter 2 explores how different threats could exacerbate the supply chain vulnerabilities identified in Chapter 1, and investigates the root causes leading to them. The threats analysed in this study are: persistent pandemics exemplified by the COVID-19 crisis (section 2.1) and extreme weather events, geo-political uncertainty and tensions, and cyber threats (section 2.2).

Section 2.1: Inventory of problems resulting from COVID-19

Section 2.1 assesses the current problems for critical supply chains observed in the context of the COVID-19 crisis (representing the "persistent pandemics" threat scenario).

The study finds that COVID-19 pandemic has presented significant challenges, and has been a stress test to the EU energy system. Nonetheless, more than one year into the pandemic, **the continued functioning of energy technology supply chains and of the energy supply within the EU demonstrates a considerable level of resiliency of the EU energy technology supply chains and sound business continuity plans implemented by the energy operators**. Nonetheless, **there were many impacts experienced by multiple energy technology supply chains due to measures introduced to handle the COVID-19 crisis** from the implementation of social distancing measures and border control measures, although the experience for each supply chain is different. Some of the major direct impacts of the COVID-19 pandemic are the disruption of trade flows and of the flow of specialised workers and experts due to border closures and stricter border controls. The rapid changes in the border control protocols and processes, due to the rapidly changing pandemic situation, also brought about challenges to cross-border trade flows within the EU. Trade flows of the EU with non-EU countries, for example with China and more broadly Asia, were able to resume earlier than intra-EU trade, as the pandemic began earlier in these non-EU countries, which have managed the crisis and resumed operations and trade earlier. Therefore, in some cases intra-EU trade flow disruptions impacted energy technology supply chains more than trade flows with non-EU countries. For example, ICT components saw 74% of deliveries affected by the border control measures put in place; while China and other Asian countries addressed the pandemic early on and limited the impacts to the supply chain to various degrees. The production volume in the heating, ventilation and air conditioning sector was also disrupted due to social distancing measures in the EU. Further, there was also disruption in the flow of energy professionals within the EU as border controls and restrictions were placed on 'non-essential' travels. This led to delays in new construction and operations and maintenance works for hydropower plants, wind, and nuclear energy sectors.

Section 2.2: Assessment of current and potential problems for critical energy technology supply chains

Section 2.2 considers three other potential external threat scenarios: extreme weather events, cyber threats and geo-political tensions, which are considered as key threats to critical supply chains.

Discussions with EU industry associations of the concerned supply chains indicated that many have neither considered nor assessed the impact of these threat scenarios on their supply chains, even when they are aware of and manage direct risks to their assets in their business continuity plans. While some of these impacts could be fully or partially mitigated at the company level, for example by improving supplier management processes, other threats, such as cyber threats, would require a collective effort, such as at the national, industry or EU level. In this regard, our analysis shows that there is still room for the European institutions and actors to further assess significant threats to the EU energy technology supply chains and develop corresponding measures.

Further analysis also revealed that while all four threat scenarios may differ in characteristics, they may lead to similar impacts to the supply chains, which could be traced to common root causes. **Supplier concentration, in both EU and non-EU countries, as well as import reliance are**

common root causes of vulnerability to pandemics, extreme weather and geo-political tensions for the EU energy technology supply chains, although the level of risks differs per supply chain, supply chain stage, individual element, and threat scenario.
The root causes of vulnerabilities for cyber threats are distinctly different from the other three threat scenarios. The presence of cyber vulnerabilities indicates the need to further consider supply chain-related cybersecurity risks at the company level as well as within the EU regulatory frameworks, for both information technology and operational technology.

Chapter 3: Possible measures to increase the resilience of the critical supply chains

Chapter 3 develops a set of policy measures to mitigate the risks associated with the four identified threat scenarios and to strengthen the resilience of the critical energy supply chains, focusing on EU-level measures.

Based on the analysis conducted in chapters 1 and 2, we conclude that the vulnerabilities to external events such as pandemics, extreme weather, and geo-political tension stem most frequently from two major root causes: dependence on non-EU suppliers in combination with high market concentration. To address these in order to increase the energy supply chains resilience, a common logic can be followed:

1. Encourage **substitution, whenever possible,** of the critical elements used in EU energy technologies supply chains. This involves a coordinated R&I effort by EU companies, academia and policy makers and can provide results only in the medium- to long-term;

Then, when dependency on the critical elements cannot be reduced:

2. **Diversify primary supply** (intra-EU and from third countries) and develop **back-up supply sources** for raw materials as well as manufactured components**,** this being a pivotal element given the EU external dependence on critical elements cannot be fully reduced or only in the long-term. Attention should be given to ensure that the EU sources materials and components from responsible sources, with adequate environmental and human rights protection;
3. **Develop secondary supply of critical raw materials** as far as possible**,** i.e. recycling, in order to further reduce the external dependence on these critical raw materials, in coordination with other circular economy measures;
4. Develop **EU supply capacities** considering available resources, economic feasibility and social and environmental impacts. While the development of EU mining, processing and recycling of raw materials or manufacturing of critical components should be feasible to various extents, fully eliminating the EU dependence on non-EU sources would likely not be feasible or advantageous given economic, social and environmental considerations;
5. **Mitigate** the risk of disruption of the chains that cannot be diversified, through cooperation with non-EU governments and critical suppliers;
6. Finally, **ensure continuity of supplies and manufacturing** in case of emergencies, through cooperation and other applicable measures where possible, such as emergency stocks.

Cybersecurity vulnerabilities are of a different nature, and therefore require a specific approach:

7. Fostering voluntary / mandatory requirements for businesses conducting supply chain management processes to ensure the integrity of their supply chain for Information Technology (IT) and Operational Technology (OT) systems, products and services.

To increase the resilience of energy technology supply chains following the above logic, six problem areas are identified, reflecting the analysis of the vulnerabilities of critical supply chains developed in chapter 2. Seven policy recommendations are then developed, addressing one or more of the problem areas. This allows to identify problems which are common to multiple supply chains and to develop horizontal measures addressing vulnerabilities in multiple supply chains, if applicable. These horizontal measures can complement supply chain-specific measures which are better tailored to address problems which are not encountered in other critical supply chains. The table below presents the problem areas and the correspondent policy recommendations.

Table 0-2 Main problem areas and correspondent policy recommendations

Main problem area with underlying root causes	Correspondent policy recommendation
1. There are knowledge gaps regarding vulnerabilities of strategic energy technology supply chains	• **Recommendation 1:** Set up an integrated system for monitoring and reporting of

Main problem area with underlying root causes	Correspondent policy recommendation
	vulnerabilities for critical energy technologies and supply chains • **Recommendation 2:** Leverage diplomacy and trade measures
2. There is a high external dependence for a number of critical raw materials from specific supplier countries, with high supplier concentration and limited EU-based primary production for a number of materials, and gaps in trade framework	• **Recommendation 2:** Leverage diplomacy and trade measures • **Recommendation 3** Develop EU-based production of raw and processed materials
3. There is a high external dependence for a number of vulnerable components for critical supply chains, with limited EU-based manufacturing, high supplier concentration, and gaps in trade framework	• **Recommendation 2:** Leverage diplomacy and trade measures • **Recommendation 4:** Leverage EU alliances to address supply chain risks
4. EU companies in critical energy technology supply chains are not fully aware of vulnerabilities and threats nor have developed mitigation and emergency measures	• **Recommendation 5:** Improve risk assessment and management by relevant entities
5. Product-specific ecodesign regulations can impact the external dependence on vulnerable components (positively or negatively)	• **Recommendation 6:** Continue the analysis of supply chain vulnerable elements in preparatory studies for ecodesign product-specific regulations
6. There is a need to develop circular economy measures such as recycling, material substitution and other efficiency measures	• **Recommendation 7:** Further integrate circular economy measures (recycling & substitution)

Each policy recommendation is detailed in chapter 3 regarding the problem, the existing policy instruments and corresponding policy gap, the need and value added of intervention at the EU level, the description of the recommendation and the discussion of its impacts. The recommendations are broken down in more specific elements, namely:

1. **Recommendation 1: Set up an integrated system for monitoring and reporting of vulnerabilities for critical energy technologies and supply chains**
   - 1.1. Set up a mechanism for integrated monitoring and reporting of vulnerabilities for critical energy technologies and supply chains
   - 1.2. Address the missing critical raw materials in the Raw Materials Information System material profiles and update regularly, especially those with an expected strong increase in consumption due the EU or even worldwide uptake of strategic energy technologies
   - 1.3. Expand the scope of the JRC Foresight Study on Critical Raw Materials for strategic technologies and sectors in the EU
   - 1.4. Continue the identification and monitoring of vulnerable elements for critical supply chains for the transition towards 2050 in the work of the Low Carbon Energy Observatory, via the next annual reports, and possibly add gas infrastructure and turbines, which are not yet addressed in the competitiveness Progress Report
   - 1.5. Mainstream energy technologies to be tackled in the various actions set in the Commission's communication on "Critical Raw Material Resilience: Charting a Path towards greater Security and Sustainability" (COM(2020) 474)
2. **Recommendation 2: Leverage diplomacy and trade measures**
   - 2.1. Develop additional coalition building & increasing diplomatic outreach, focusing on regions or countries of high importance to the EU critical energy supply chains
   - 2.2. Further mainstream environmental and social (incl. human rights) aspects into free trade agreements and other international frameworks
   - 2.3. Further adapt the free trade agreement chapters under negotiation on energy and raw materials concerning aspects related to critical energy supply chains
3. **Recommendation 3: Develop EU-based production of raw and processed materials**
   - 3.1. Include explicit work on the most critical raw materials for the energy systems into the workstreams of, for example, the EIT Raw Materials and, when possible, under the action

points from the CRM Action Plan to more easily identify key mining priorities within the EU for the energy system

3.2. Ensure that EU-based programmes and instruments encourage alignment between the needs of industry and EU-based production of raw materials when identifying mining and processing projects in the EU that can be operational by 2025 through promoting knowledge-sharing and bringing different stakeholders together

4. **Recommendation 4: Leverage EU alliances to address supply chain risks**

    4.1. Ensure existing EU alliances contribute to increasing the resilience of critical energy supply chains – where relevant, and address more systematically supply risks and exposure to threats, and international trade relationships

    4.2. Consider candidates for new alliances or adaptation of the scope of existing alliances. However, such alliances should be preferentially focused on emerging technologies and applications, hence especially battery and hydrogen. Other potential alliances for mature technologies such as for semiconductors should avoid subsidies infringing WTO rules

5. **Recommendation 5: Improve risk assessment and management by relevant entities**

    5.1. Provide a guidance for EU energy companies assessing and managing supply chain-related risks. This guidance (of voluntary nature by definition) would detail the methodology as well as provide examples of how to assess technology supply chains

    5.2. Leverage the CER and NIS 2 Directive proposals to ensure relevant entities conduct the risk assessment and implement corresponding measures. The CER and the NIS 2 Directives proposals do contain specific requirements for relevant entities to do so, and furthermore require or empower the Commission to detail the methodology for complying with those requirements through implementing acts

6. **Recommendation 6: Continue the analysis of supply chain vulnerable elements in preparatory studies for ecodesign product-specific regulations**

    6.1. Maintain and enhance, where necessary, the detailed analysis in the preparatory studies of impacts of ecodesign requirements on the product and vulnerable elements of the supply chain. If the ecodesign requirements are found to have significant impacts (positive or negative) regarding demand for vulnerable components, their production in the EU and trade (especially with non-EU partners), they should be taken up in the Commission Impact Assessment, as is currently the case

7. **Recommendation 7: Further integrate circular economy measures (recycling & substitution)**

    7.1. when conducting all CEAP actions (including when developing a sustainable product policy legislative initiative), it is recommended to identify further product groups based on their environmental impact and circularity potential, while giving priority to product groups identified in the context of the critical energy value chains, in addition to electronics, ICT and batteries, wind energy, solar PV, such as gas infrastructure, hydrogen electrolysers and stationary fuel cells

    7.2. when carrying out the next revision involving material-efficiency aspects of the Methodology for the Ecodesign of Energy-related Products (MEErP) study, further explore extending the scope to new materials that are relevant for the purpose of the critical energy supply chains, and consider substitution (in the frame of RD&I) not only to replace hazardous substances, but also to replace substances with important supply chain risks. The same extension should be considered for the upcoming Sustainable Product Initiative

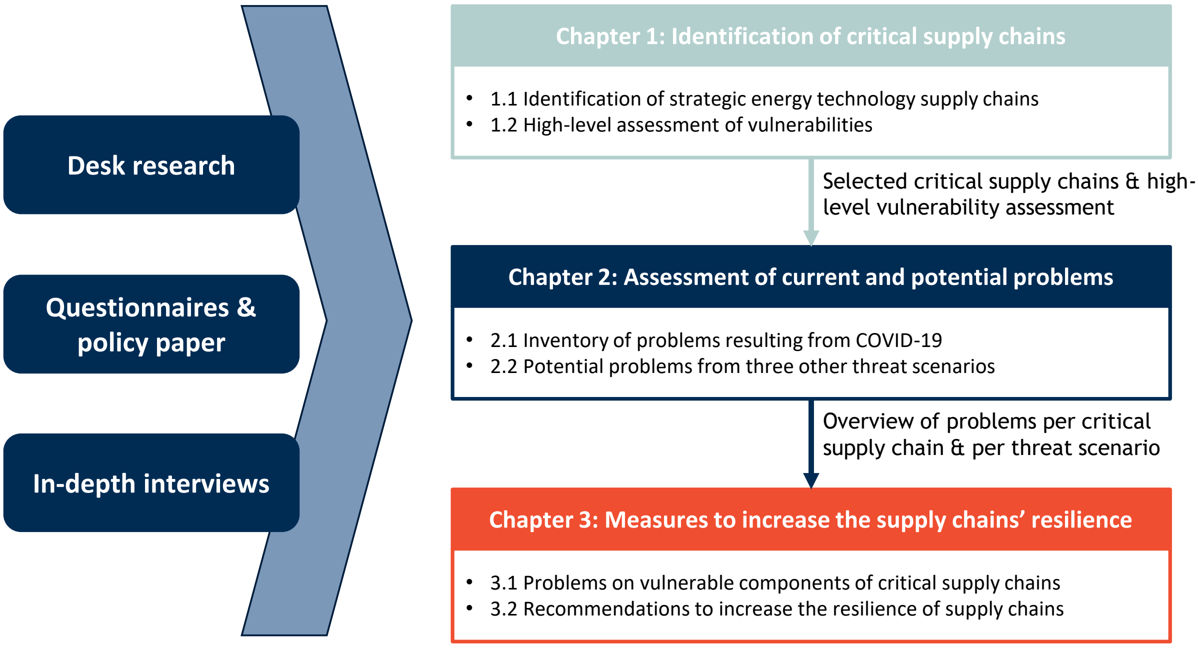
INTRODUCTION

The study aims to, first, identify the critical energy technology supply chains for ensuring the EU security of energy supply and the clean energy transition, assessing any vulnerabilities of and potential threats to the supply chains. The second objective is to identify policy measures to increase the resilience of these critical energy technology supply chains, building, among others, on the observed COVID-19 impacts and other potential external threat scenarios. The study does not analyse energy commodity[2] supply chains.

Figure 0-3 presents the structure of this study, which is as follows:

- **Chapter 1** identifies critical energy technology supply chains and then conducts an assessment of the vulnerabilities of these supply chains;
- **Chapter 2** assess current and potential problems for the critical supply chains, making an inventory of issues caused by the COVID-19 crisis and three other potential threat scenarios (extreme weather events, geo-political uncertainty and tensions, and cyber threats);
- **Chapter 3** identifies potential measures to mitigate risk and to increase the resilience of the critical EU energy supply chains.

Figure 0-3 Overview of overall study structure and methodology



As shown, the study employed a diverse range of approaches to identify critical supply chains, assess their vulnerabilities and potential problems due to a number of threats, and identifying measures to increase the resilience of the supply chains. The methods comprise extensive desk research and consultation of experts for each critical supply chain (in the form of an online questionnaire, in-depth interviews and further written feedback). Annex A presents in detail the study methodology.

This study focuses on energy technology supply chains, defined here as *the combination of all the elements (raw and processed materials/(sub-)components/equipment/services or skills) necessary for a specific energy technology.*

As depicted in Figure 0-4, we define critical supply chains for the energy sector as those with a:

- **Strategic importance to the EU** clean energy transition and/or to guarantee the security of energy supply; and a
- **High vulnerability**, regarding the entire supply chain, or specific stages (construction & installation, decommissioning) or elements (e.g. raw & processed materials, or a certain expertise for O&M, a sub-components).

[2] Examples of energy commodities are electricity, natural gas and oil products. Therefore, production, trade and consumption of these commodities are out of scope of the study, which focuses on the technologies which enable those activities.

Figure 0-4 Necessary conditions for supply chain criticality

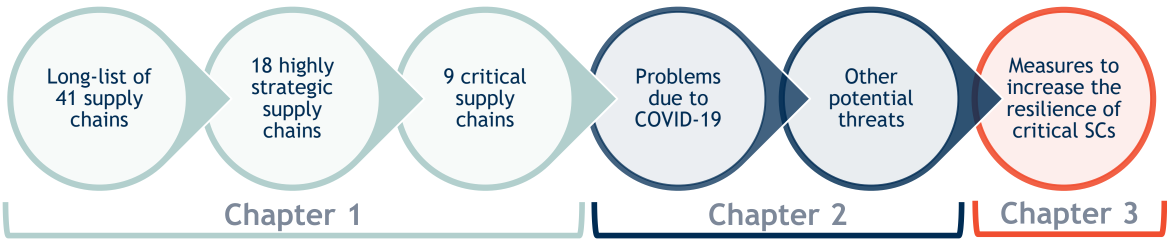
In addition to critical supply chains, a number of concepts are defined and applied consistently throughout the study. These are summarised in Table 0-3.

Table 0-3 Summary of concepts for the purpose of this study

Concept	Definition
Energy technology supply chain	The combination of all the elements (raw and processed materials/(sub-)components/equipment/services or skills) necessary for a specific energy technology.
Critical supply chain	A supply chain - Considered of strategic importance for the EU; and - With high vulnerability for specific supply chain elements.
Strategic importance	Importance to ensure security of energy supply (now and/or in 2050) and/or to the EU to attain its 2050 GHG emission reduction targets
Vulnerability	Level of sensitivity/exposure to external disruptions to the supply chain
Supply chain element	A raw and processed material, equipment, (sub-)component, services or skills employed in a supply chain
Supply chain stage	One of the steps of the supply chain: raw & processed materials production, manufacturing, transport, construction & installation, operation & maintenance or decommissioning & circularity

In chapter 1, starting from a long-list of 41 energy technology supply chains, 9 critical supply chains are identified according to the definition above. Chapters 2 and 3 then assess the problems and develop measures to increase the resilience of these supply chains. Nonetheless, the measures proposed in chapter 3 may serve to increase the resilience of the entire EU energy system, and not only the critical supply chains analysed in this study.

Figure 0-5 Process to identify critical supply chains, assess problems due to COVID-19 and other threats, and develop policy measures



This study is based on data from publicly available documents as well as inputs received from stakeholders through the online survey, interviews and feedback to written material. The level of detail provided for certain supply chains is thus constrained by the available information. This may in certain cases indicate a lack of attention by the stakeholders to the issues analysed in this study. Therefore, the study also helps pinpointing vulnerable elements of critical energy technology supply chains for which little knowledge is available. Moreover, this study focuses on a number of supply chains considered most critical due to the need to concentrate the available study resources. This does not mean other energy technologies are not important to the EU energy system nor that their supply chains don't exhibit vulnerabilities.

1. IDENTIFICATION OF THE CRITICAL SUPPLY CHAINS FOR THE ENERGY SECTOR

Following the methodology presented in Annex A, this chapter first defines a list of strategic energy technology supply chains (section 1.1) and then conducts an assessment of the vulnerability of strategic supply chains in order to define the list of critical supply chains (section 1.2).

1.1. Identification of strategic energy technology supply chains

Main findings of Section 1.1

- Strategic energy technology supply chains are identified according to their contributions to the current and future EU security of energy supply and/or the clean energy transition
- Employing data from the 1.5TECH scenario of the Long-Term Strategy and complementary sources, 18 energy technology supply chains are identified as highly strategic to the EU:
    - Wind – onshore/offshore
    - Solar PV
    - Hydropower
    - Nuclear fission
    - Combined cycle / open cycle gas turbines
    - Biomass – gaseous fuels
    - Electrolytic hydrogen
    - Gas networks[3]
    - Gaseous fuels storage
    - Liquefied gas terminals
    - Electricity networks
    - Batteries – mobile/stationary
    - Hydro pump storage
    - Battery EVs, recharging stations, smart charging and vehicle-to-grid
    - Fuel cell vehicles and hydrogen refuelling stations
    - Smart buildings & automation (incl. heating, ventilation and air conditioning)
    - Heat pumps
    - Digital technologies
- Each supply chain is considered strategic for a specific reason. Most often it is due to future contributions to the energy transition and/or security of energy supply, while some are already contributing to current security of supply;
- There is a good match between this study's list of highly strategic supply chains and feedback from stakeholders;
- A number of supply chains are also identified as 'strategic' in the analysis, but not 'highly strategic' and thus not short-listed, such as hydropower, heat pumps, biomass-gaseous fuels. This recognises their contributions and highlights that other technology supply chains are still relevant to the present and/or future EU energy system. They were not further assessed in the rest of the study (section 1.2 forward).

The identification of the strategic supply chains follows three steps:
- Development of a long-list of supply chains (section 1.1.1);
- Assessment of the strategic importance of these supply chains (section 1.1.2);
- Selection of the strategic supply chains (section 1.1.3).

1.1.1. Development of a long-list of supply chains

The long list in Table 1-1 covers a wide range of supply chains in the energy system categories of energy supply, transmission & distribution, storage and consumption. The development of the list of strategic supply chains considered the following EU documents and strategies in order to guarantee that all relevant supply chains for the future security of supply and decarbonisation of the EU energy system were included:
- Climate Target Plan Impact Assessment;
- European long-term strategic vision: In-depth analysis;
- EU Strategy for Energy System Integration;
- Hydrogen strategy for a climate-neutral Europe;
- IPCEIs: Strengthening strategic value chains for a future-ready EU industry;

[3] Gas networks, liquefied gas terminals and gaseous fuels storage refers to both methane and hydrogen gases

- InvestEU Regulation proposal;
- SET-Plan;
- In-depth study of European Energy Security.

Due to the large number of industry-specific technologies and the resources available to this study, industry end-use processes supply chains were not surveyed specifically. While industry decarbonisation is critical for the energy transition, the large number of industry-specific technologies would lead to a lower strategic importance compared to more widespread supply chains.

Table 1-1 List of aggregated supply chains

Category	Technology supply chain
Energy supply	
Electricity generation	Wind – onshore and offshore
	Solar photovoltaics
	Concentrated solar power
	Hydropower
	Ocean energy
	Geothermal – for power
	Nuclear fission
	Combined cycle gas turbines (CCGT) / Open cycle gas turbines (OCGT)
	Coal (conventional/advanced/integrated gasification combined cycle)
Heat generation[4]	Geothermal – for heat
	Solar Thermal
	Waste heat recovery
Other energy supply	Fossil-based energy supply + CCU/S
	Bio-energy carbon capture and storage (BECCS)
	Biomass combined heat and power (CHP) – for all biomass forms
	Other combined heat and power
	Biomass – liquid fuels
	Biomass – gaseous fuels
	Electrolytic hydrogen
	Hydrogen from steam methane reforming
	Other renewable fuels of non-biological origins (RFNBOs)
	Other decarbonised fuels / recycled carbon fuels (RCF)
	Oil production – onshore and offshore
	Natural gas production – onshore and offshore
Energy transport	
Gas	Gas networks (transmission and distribution)
	Liquified gas terminals
Electricity	Electricity networks (transmission and distribution)
District heating and cooling	DHC infrastructure (pipelines, circulators & other equipment)
Energy storage	
Storage	Batteries – mobile/stationary
	Hydro pump storage
	Hydrogen storage (for electricity)
	Liquid new fuels (e-liquids) storage
	Gaseous fuels storage
	Thermal storage

[4] Heat pumps are addressed in energy consumption.

Category	Technology supply chain
Energy consumption	
Transport	Battery EVs/recharging stations/smart charging/vehicle-2-grid components
	Fuel cell vehicles/hydrogen refuelling stations
Buildings	Smart buildings & automation
	Heat pumps
	Efficient appliances and equipment
	Building shell
Overarching enabling technologies	
Overarching	Digital technologies - telecom, sensors, meters, control & cybersecurity

1.1.2. Strategic importance assessment of the list of energy technology supply chains

The criteria to define the strategic importance are summarised in Annex A and are applied to the long list (see Table 1-1) of supply chains. The main data source of this exercise is the long-term strategy analysis of the European Commission, published in 2018.[5] The EU energy system pathway to 2050 is characterised by high uncertainty. Therefore, the long-term (2050) share indicator for each technology does not intend to affirm what will be the actual level of deployment. It rather serves to identify strategic energy technology supply chains which are poised to play an important role in the future EU energy system, even if there is still uncertainty on exactly how much.

For the purpose of this study, we adopt the decarbonisation scenario of 1.5TECH, which reflects the ambition to reach a net zero emission of greenhouse gases in 2050, thereby pursuing efforts to limit temperature increase to 1.5°C. The 1.5TECH scenario also relies further on energy technologies to reach the net zero emissions target in 2050, compared to other transition pathways. In particular, it partly relies on the deployment of carbon capture and storage (CCS), and bio-energy with carbon capture and storage (BECCS) technologies.

The following sections present the results of the assessment of the strategic importance to the EU of supply chains, per category, based on desk research, the results of the survey and other stakeholder inputs. The methodology employed is summarised in Textbox 1-1.

Textbox 1-1 Summary methodology for assessing the strategic importance of supply chains

Four indicators were used to assess the importance of energy technologies to the EU security of energy supply (in the short- and long-term) and the clean energy transition (in the long-term). The indicators 1 and 2 are quantitative, while indicators 3 and 4 are qualitative:

- Indicator 1. Current share of energy supply / transport / storage / consumption
- Indicator 2. Long-term share of energy supply / transport / storage / consumption
- Indicator 3. Ability to provide flexibility services to the energy system
- Indicator 4. Policy priorities / other contributions not overviewed

Thresholds were set for classifying the energy technology as “of limited importance” / “important” / “very important” for the indicators 1 and 2, with the threshold value being set to short-list a manageable number of supply chains as highly strategic (threshold is 8% of the final energy consumption for supply / storage / energy transport supply chains and 8% of sector final energy consumption for end-use technologies). The qualitative indicator 3 identifies whether the individual supply chains provide flexibility in seasonal/daily timeframes or peak scarcity hours. Indicator 4 employs an ad hoc assessment tailored to each technology supply chain, where deemed relevant.

The criteria for selection are therefore that an energy technology and its supply chain are considered:

- Highly strategic if it is very important according to any of the indicators;
- Strategic if it is important according to any indicators;
- Not strategic otherwise.

[5] European Commission. (2018). ‘In-depth analysis in support of the Commission Communication COM(2018)773 A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy’. Available from: https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf

The full methodology is presented in Annex A, while details on the calculation of the strategic importance indicators as well as any assumptions per supply chain are presented in Annex C.

Energy supply

The following supply chains within the category of 'energy supply' in Table 1-1 have been identified to be highly strategic to the EU, based on the criteria for identifying strategic supply chains and according to the selection process as explained in Annex A:

- ✓ Wind – onshore/offshore
- ✓ Solar PV
- ✓ Hydropower
- ✓ Nuclear fission
- ✓ Combined cycle gas turbines (CCGT) / Open cycle gas turbines (OCGT)
- ✓ Biomass – gaseous fuels
- ✓ Electrolytic hydrogen

Table 1-2 provides an overview of the supply chains in energy supply, where the percentages presented express the level of contribution of each of these to the total final energy consumption. The sum of percentages to the current share are significantly under 100%, as a large part of the current EU final energy consumption is met through energy imports (commodity, i.e. fuel supply chains are out of the scope of the study). Also, the sum of percentages for the long-term share slightly surpasses 100% due to calculation approximations, potential overlaps between some supply chains (e.g. natural gas production and gas-fired power generation), and energy losses which make primary energy production larger than final consumption.

Nonetheless, the indicators are comparable both between supply chains and between the current and long-term shares as they are expressed in percentages and not absolute terms. Small differences in the indicators do not lead to changes in the list of strategic supply chains, also as a supply chain is usually considered highly strategic due to several indicators (e.g. electrolytic hydrogen) or due to a clear contribution to the current energy system or the energy transition much above the thresholds defined in Annex A.

Table 1-2 Strategic importance of the long list of supply chains in the category of 'energy supply'

	Supply chain/technology	Strategic?	Current share	Long-term share (2050)	Flex. provision (2050)	Qualitative aspects
			Energy supply			
Electricity	Wind – onshore/offshore	HS	2.0%	26.0%		
	Solar PV	HS	~1%	8.0%		
	Concentrated solar power		0.0%	1.0%		
	Hydropower	HS	2.7%	5.5%	Seas. / Scarcity h.	
	Ocean energy		0.0%	0.0%		
	Geothermal – for power		0.1%	0.2%		
	Nuclear fission	HS	6.8%	6.5%	Seas. / Scarcity h.	High share of supply for some MSs
	CCGT/OCGT	HS	4.2%	4.2%	Seas. / Scarcity h.	
	Coal (conventional / advanced / IGCC)		6.3%	0.0%		Not strategic to long-term policy goals
Heat	Geothermal – for heat		1.7%	2.0%		
	Solar Thermal		0.2%	-		
	Waste heat recovery		0.1%	3.2%		
Other supply	Fossil-based energy supply + CCU/S		0.0%	1.5%		
	BECCS	S	0.0%	4.3%		
	Biomass CHP (all biomass forms)	S	1.5%	3.0%	Seas. / Scarcity h.	
	Other CHP	S	4.6%	0.0%		
	Biomass – liquid fuels	S	1.5%	6.0%		
	Biomass – gaseous fuels	HS	1.4%	10.4%	Scarcity h.	Enables use of methane infra
	Electrolytic hydrogen	HS	0.0%	11.3%	Daily / seasonal	
	Other RFNBOs	S	0.0%	6.6%	Daily / seasonal	
	Hydrogen from SMR		2.8%	0.0%		
	Other decarbonised fuels / RCF		0.0%	0.0%		
	Natural gas production	S	7.6%	5.8%		
	Oil production	S	6.9%	0.2%		Not strategic to long-term policy goals

*Note: **HS** – Highly strategic; **S** – Strategic; **CCU/S** – Carbon Capture, Utilisation and Storage; **IGCC** – Integrated Gasification Combined Cycle; **RCF** – Recycled Carbon Fuels; **RFNBO** - Renewable Fuels of Non-Biological Origin; **SMR** –Steam Methane Reforming; **Seas. –** Seasonal; **Scarcity h. –** Scarcity hour.*
*Importance per indicator: **very important**; **important**; **limited importance***

Energy transport

The following within the category of 'energy transport' have been identified to be highly strategic to the EU, based on the process for identifying strategic supply chains:

- ✓ Gas networks (methane and hydrogen)
- ✓ Liquefied gas terminals
- ✓ Electricity networks

Table 1-3 provides an overview of the supply chains in energy transport. The collective share of energy from gaseous fuels remains significant in the long-term, especially due to the increasing penetration of hydrogen and e-gases in the 1.5TECH scenario, in addition to biomethane. Therefore, the supporting infrastructure (gas network and liquefied gas terminals) is assessed as highly strategic to the EU. Similarly, electrification is a main decarbonisation strategy, and so electricity transport will play a crucial role in the decarbonisation of the energy sector, at transmission and distribution levels. While district heating and cooling networks are considered strategic, their present and future contributions to the energy system are not important enough, in relative terms, to classify those as highly strategic.

Table 1-3 Strategic importance of the supply chains in the category of 'energy transport'

Supply chain/technology		Strategic?	Current share	Long-term share (2050)	Flex. provision (2050)	Qualitative aspects
	Energy transport					
Gas	Gas networks	HS	34.4%	37.4%	All timeframes	
	Liquified gas terminals	HS	8.4%	1.9%		
Electricity	Electricity networks	HS	21.8%	50.1%	All timeframes	
Heat & cool	District heating and cooling	S	4.2%	4.7%		

*Note: **HS** – Highly strategic; **S** – Strategic.*

Energy storage

The following supply chains within the category of 'storage' have been identified to be highly strategic to the EU:

- ✓ Batteries—mobile/stationary
- ✓ Hydro pumped storage
- ✓ Gaseous fuels storage[6]

Table 1-4 below provides an overview of the supply chains in the energy storage, where the percentages presented express the level of contribution of each of these supply chains to the total final energy consumption. Batteries are forecasted to see significant grow to 2050, hydro pumped storage will also increase its participation, and gaseous fuel storage proportion to final energy consumption will decrease. Nonetheless, all three technologies will remain highlight strategic for the provision of flexibility, especially in the daily and scarcity hours timeframe (batteries and hydro pumped storage) and seasonal timeframe (gaseous fuels storage).

Table 1-4 Strategic importance of the supply chains in the category of 'energy storage'

			Baseline	2050		
Supply chain/technology		Strategic?	Current share	Long-term share (2050)	Flex. provision (2050)	Qualitative aspects
	Energy storage					
Storage	Batteries – mobile/stationary	HS	0.2%	9.2%	Daily / Scarcity h.	
	Hydro pump storage	HS		0.6%	Daily / Scarcity h.	
	Hydrogen storage (for electricity)		0.0%	1.3%		
	Liquid new fuels storage	S	1.5%	6.0%		Limited repair needs
	Gaseous fuels storage	HS	5.5%	4.7%	Seas.	
	Thermal storage		0.8%	0.9%		

*Note: **HS** – highly strategic; **S** – Strategic.*

Energy consumption

The following supply chains within the category of 'energy consumption' have been identified to be highly strategic to the EU:

- ✓ Battery electric vehicles and associated technologies (recharging stations/smart charging/Vehicle-to-Grid - V2G)
- ✓ Fuel cell vehicles and hydrogen refuelling stations (HRS)
- ✓ Smart buildings and building automation
- ✓ Heat pumps

Table 1-5 provides an overview of the supply chains in the end-use sectors of transport and buildings. The percentages for transport presented refer only to the level of contribution of each of these supply chains within the transport sector itself, and not to the total final energy consumption. In the case of building technology supply chains which increase the energy efficiency of buildings, the percentages refer to the overall energy savings in buildings compared to the final energy consumption. The details on the calculation as well as any assumptions are presented in Annex C.

As electric vehicle components, the recharging stations and charging/vehicle-to-grid technologies are closely linked and interdependent, they are considered as one combined supply chain. Similarly, fuel

[6] Gas networks, liquefied gas terminals and gaseous fuels storage refers to both methane and hydrogen gases

cells and hydrogen refuelling stations are considered as a single supply chain. Each of these supply chains are further disaggregated in the analysis to identify specific vulnerabilities, if necessary.

Efficient appliances and equipment as well as building shell technologies cover a broad range of technologies and furthermore their strategic importance is related to their contributions to energy savings in buildings, with the technologies thus making passive contributions (once installed) to the energy transition / security of supply. Therefore, these qualitative considerations lead to these supply chains being categorised as 'strategic' instead of 'highly strategic'.

Table 1-5 Strategic importance of the supply chains in the category of 'Energy consumption'

Supply chain/technology		Strategic?	Current share	Long-term share (2050)	Flex. provision (2050)	Qualitative aspects
	Energy consumption					
Transport	Battery EVs/recharging stations/smart charging/V2G	HS	1.3%	25.9%	Daily	
	Fuel cell vehicles/HRFs	HS	0.0%	15.8%	Daily	
Buildings	Smart buildings & automation (incl. HVAC)	HS	0.0%	9.4%	Daily	
	Heat pumps	HS	2.2%	>15%	Daily	Enables electrification with renewables
	Effcient appliances and equipment	S	34.3%	11.0%		Passive / broad range of techs.
	Building shell	S	NA	39.0%		

*Note: **HS** – Highly strategic; **S** – Strategic; **V2G** – vehicle-to-grid; **HVAC** – heating, ventilation and air conditioning.*

Overarching enabling technologies

Digital technologies (telecom, sensors, meters, control & cybersecurity) supply chains within the category of 'overarching enabling technologies' have been identified to be highly strategic to the EU. These technologies have been identified to be enablers of all assets, and are essential to the effective functioning of energy supply chains within the EU. Given the broad scope (e.g. smart sensors and meters, industrial control systems, distribution management systems, and many other applications), this supply chain is analysed in detail in the subsequent sections, covering applications in all strategic supply chains.

Table 1-6 Strategic importance of the supply chains in the category of 'Overarching enabling technologies'

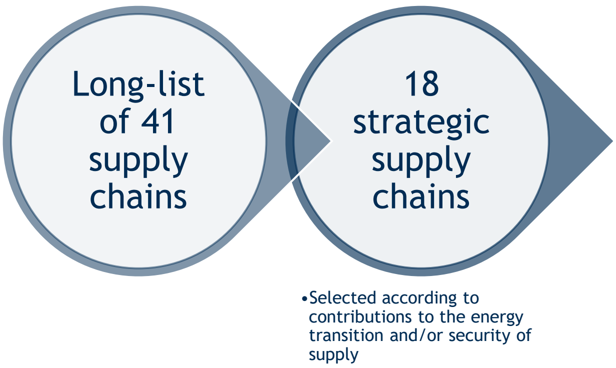
Supply chain/technology		Strategic?	Current share	Long-term share (2050)	Flex. provision (2050)	Qualitative aspects
Enabling	Digital technologies	HS	Restricted	Enabler of all assets		

*Note: **HS** – highly strategic; **S** – Strategic.*

1.1.3. Selection of the strategic supply chains

In summary, a total of 18 supply chains have been identified as highly strategic to the EU in the long-term, as listed in Table 1-7. This selection was made from a long-list of 41 supply chains, as illustrated in Figure 1-1.

Figure 1-1 Supply chain analysis process until the definition of strategic SCs



The supply chains which are identified as highly strategic are selected if any of the indicators of the current and future share indicates a value of ≥8%, if they make significant contributions to the security of supply in 2050, or due to other qualitative aspect (to adequately consider EU energy & climate priorities and the feedback received from stakeholders – see Annex A). Therefore, supply chains are selected which are important to the security of supply today, as well as those which are foreseen to contribute significantly to the clean energy transition or the security of supply in the long-term. The combination of indicators reflecting the present and long-term horizons allows to select the main supply chains for energy supply, transport, storage and consumption. Moreover, a number of supply chains are also identified as 'strategic' in the analysis above (but not 'highly strategic' and thus not short-listed here). This also recognises their contributions, and serves to highlight that other technology supply chains not listed below are still relevant to the present and/or future EU energy system.

Table 1-7 Summarised list of highly strategic supply chains

Supply chain/technology	Current share	Long-term share (2050)	Flex. provision (2050)	Qualitative aspects
Wind – onshore/offshore	2.0%	26.0%		
Solar PV	~1%	8.0%		
Hydropower	2.7%	5.5%	Seas. / Scarcity h.	
Nuclear fission	6.8%	6.5%	Seas. / Scarcity h.	High share of supply for some MSs
CCGT/OCGT	4.2%	4.2%	Seas. / Scarcity h.	
Biomass – gaseous fuels	1.4%	10.4%	Scarcity h.	Enables use of methane infra
Electrolytic hydrogen	0.0%	11.3%	Daily / seasonal	
Gas networks	34.4%	37.4%	All timeframes	
Liquified gas terminals	8.4%	1.9%		
Electricity networks	21.8%	50.1%	All timeframes	
Batteries – mobile/stationary	0.2%	9.2%	Daily / Scarcity h.	
Hydro pump storage		0.6%	Daily / Scarcity h.	
Gaseous fuels storage	5.5%	4.7%	Seas.	
Battery EVs/recharging stations/smart charging/V2G	1.3%	25.9%	Daily	
Fuel cell vehicles/HRFs	0.0%	15.8%	Daily	
Smart buildings & automation (incl. HVAC)	0.0%	9.4%	Daily	
Heat pumps	2.2%	>15%	Daily	
Digital technologies	Limited	Enabler of all assets		

Note: ***Scarcity h.*** *– Scarcity hour.*

Figure 1-2 Overview of strategic energy technology supply chains and other supply chains considered

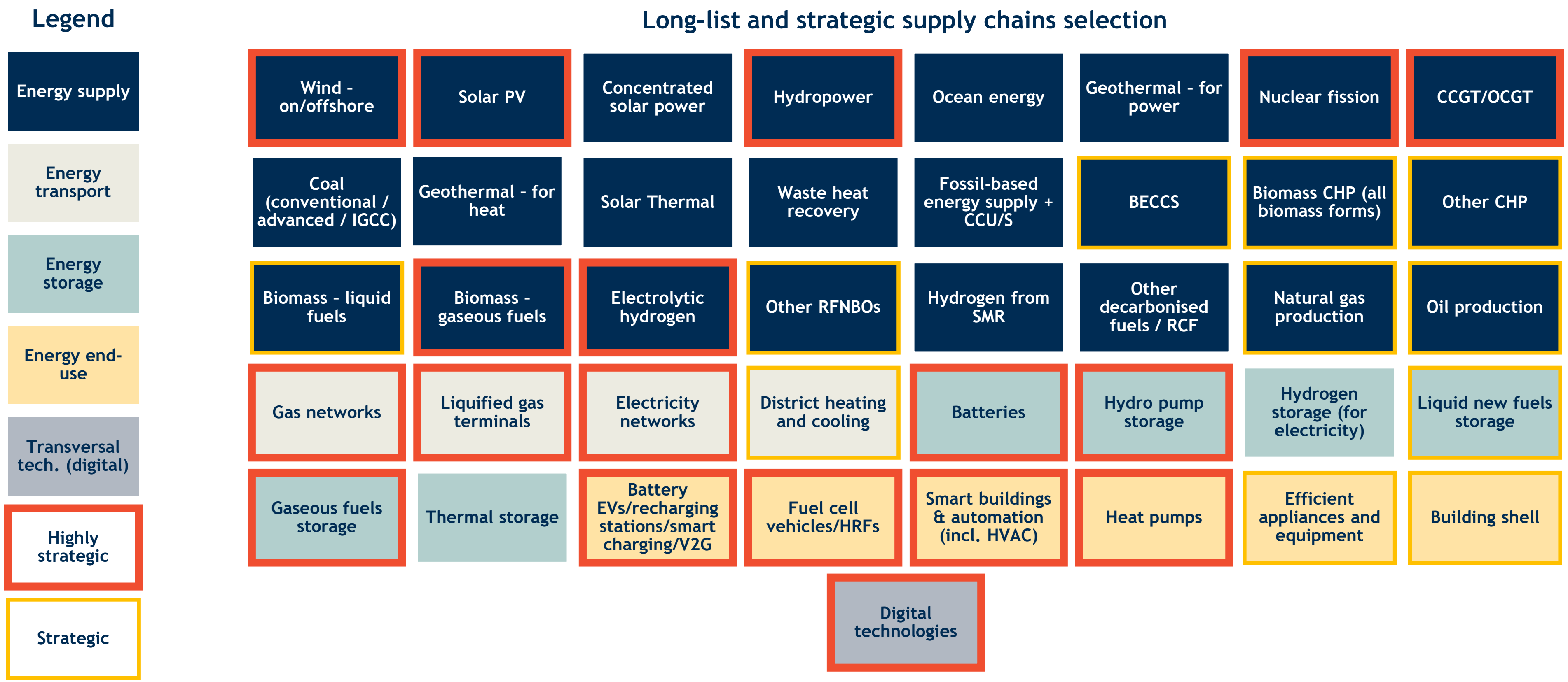
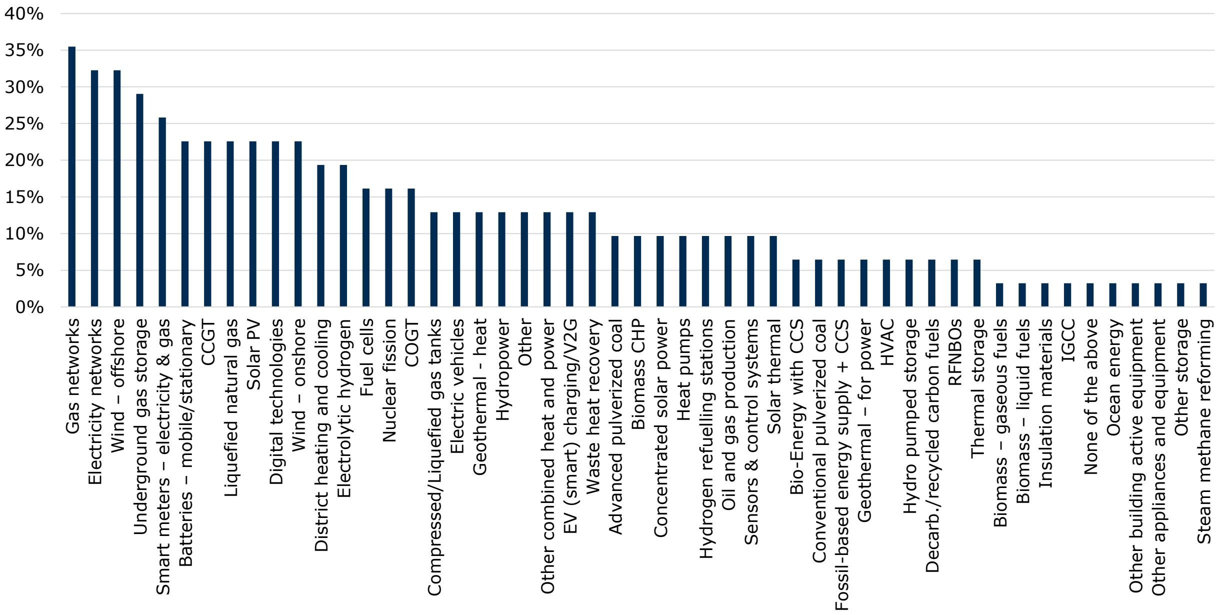


Figure 1-3 presents the frequency with which supply chains were indicated as strategic by survey respondents. It must be considered that the results are affected by the profile of the respondents (which are not fully representative of the whole EU energy sector), as they may be biased towards their own supply chains. Nonetheless, there is generally a good match with this study's list of highly strategic supply chains – the only supply chain ranked as strategic by more than 15% of the respondents and which is not considered highly strategic in this study is district heating and cooling. We consider it 'strategic' but not 'highly strategic', due to the indicator thresholds used and the need to maintain the number of supply chains analysed commensurate with the available resources.

Figure 1-3 Frequency with which supply chains were indicated as strategic by survey respondents ($n_{respondents}$ = 31)



The following section briefly complements the assessment of these indicators, to explain why the short-listed supply chains are highly strategic for the security of energy supply, for the long term climate neutrality goals and for the EU industry and economy.

Details on the strategic importance of selected supply chains

This section provides a short overview of why the supply chains have been considered as strategic, and also further details the scope of the technology (i.e. which products and services were considered), if necessary.

Further details on each of the supply chains be found in Annex B, where some of the strategic supply chains have been grouped for the subsequent vulnerability analysis (section 1.2). Therefore, the following highly strategic supply chains are grouped (section 1.2 further details the arguments for grouping the chains):

- Batteries & electric vehicles ➔ batteries;
- Electrolytic hydrogen & fuel cells/hydrogen refuelling stations (HRS) ➔ hydrogen production, storage, and end-use;
- Hydropower & pumped hydro storage ➔ hydropower and PHS;
- Biomass – gaseous fuels & OCGT / CCGT (gas turbines) ➔ biomass gasifiers and gas turbines;
- Gas networks, liquefied gas terminals and gaseous fuels storage ➔ Gas infrastructure.

Wind energy – onshore/offshore

Wind energy stands out as a technology with relatively high installed capacities currently compared to most other renewable energy technologies (except hydropower), and high expected capacity additions for both the EU and globally. Furthermore, the EU knowledge position for wind energy is very strong, with approximately 50% of publications originating from Europe, signalling a sound basis to maintain a position of global leadership for this technology. Therefore, an in-depth assessment of wind energy critical dependence issues is firmly recommended. Due to the commonalities between the critical dependencies for onshore and offshore wind, it is suggested the two technology variants be considered at the energy technology family level (wind energy).

Solar PV

A solar PV system includes one or more solar modules, and other elements such as supporting structure, cables and inverters, and is designed to produce specific power and voltage output. In 2019, the solar power sector increased at the extremely fast rate of 13% year-to-year to 116.9 GW.[7] This figure represents almost half of the global new power plant capacity installed in 2019. But in Europe, solar power amounted to around 4% of final electricity consumption.[8] According to the Long-Term Strategy, solar PV electricity generation could grow to represent 8% of the total EU final energy consumption in 2050 – around 16% of final electricity consumption.

Hydropower

Hydropower generation corresponds to about 12% of the European net electricity generation and 36% of electricity from renewable resources in Europe[9]. In 2019, the hydropower installed capacity in the EU27 was 151.4 GW (against 1 308 GW globally[10], from 1 025GW in 2010[11]). Hydropower is a controllable (or dispatchable) renewable energy source providing important flexibility to the energy system, including on the seasonal timeframe (applies particularly to reservoir hydropower). This is due to its storage capacities and some level of stochastic predictability of reservoir inflows. Hydropower is, however, variable over longer time scales, as it depends on precipitation and water run-off. With about 60 to 70% of the economically feasible hydropower potential used so far within Europe, there is still an untapped potential,[12] and its share in the EU energy supply could grow by 2050, according to the Long-Term Strategy.

Nuclear fission energy

Thirteen out of the 27 EU Member States have nuclear power plants (NPPs), which provide around a quarter of the electricity produced in the EU.[13] 4 reactors are under various stages of development in the EU27,namely in FI, FR and SK.[14] The in-depth analysis in support of the Long-Term Strategy 'A Clean Planet for All' notes a number of challenges for nuclear energy, namely "high construction costs (also linked to strict safety regulations), public acceptance issues in some Member States and increasing competitiveness of other energy sources", as well as uncertain electricity market prices. Nonetheless, the strategy envisages that by 2050 nuclear energy will provide 15% power share, to complement the over 80% electricity to be produced from renewable sources. According to the Commission, "together […], this will be the backbone of a carbon-free European power system".[15] As around 90% of the existing nuclear power plants in the EU would be permanently shut down by 2050, Member States will need to make choices regarding the replacement of the nuclear power plant fleet.[16]

Gas turbines

Gas turbines (open and closed cycle gas turbines OCGT.CCGT) are a technology based on the internal combustion engine that use gases to produce electricity. According to the IEA, the reliance on flexible natural gas-fired power generation is set to increase across the EU driven by the coal-phase-out and some countries' decision to end the use of nuclear energy. Natural gas can support the transition to cleaner fuels, including biomethane and hydrogen.[17] A recent report by the International Energy Agency (IEA), finds that the clearest example of a "quick win" to reduce emissions by fuel switching

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[7] SolarPower Europe (2020) EU Market Outlook for Solar Power 2019-2023
[8] European Commission (2020) Shedding light on energy in the EU
[9] Eurostat – Renewable energy statistics and Hydropower Europe (2020). Available at https://hydropower-europe.eu/private/Modules/Tools/EUProject/documents/2/WP4_DlRp_02_D4_3_StatusHydroTech_v4_2_Final.pdf
[10] IHA (2020) Hydropower Status Report. Available at https://www.hydropower.org/statusreport
[11] Renewable Power Generation Costs in 2019, IRENA 2020
[12] https://hydropower-europe.eu/about-hydropower-europe/vision-of-the-forum/
[13] European Parliament (2020) Nuclear energy factsheet.
[14] IAEA (2020) The Database on Nuclear Power Reactors
World Nuclear Association (2020) Nuclear Power in the European Union
[15] European Commission (2018) In-depth Analysis in Support of the Commission Communication COM(2018) 773 A Clean Planet for All
[16] European Commission (2016) Nuclear Illustrative Programme
[17] IEA (2020), European Union 2020. Available at: https://www.iea.org/reports/european-union-2020

is by running existing gas-fired plants instead of coal-fired plants for electricity generation. On average, switching from coal to gas cuts emissions by 50% when producing electricity.[18]

Biomass – gaseous fuels

The installed electricity capacity from biogas plants reached a total of just over 11 000 MW in 2018, at an average of 0.6 MW_e per plant. The electricity generated by these plants amounted to 65 TWh_e. With average electrical efficiency of 38%, this means an input of 171 TWh biogas. Biomethane production increased to 19 TWh in 2017. Different power and heat production systems based on gasification technologies have been developed during the last decades. On average, switching from coal to gas cuts emissions by 50% when producing electricity, although taking methane leakages in consideration reduces this. The EU has significant gas-fired generation capacity. This makes gas a candidate for stepping in to replace the gap left by declining coal baseload power.[19]

Electrolytic hydrogen

According to the EU's Long-Term Strategy for a climate neutral economy, the role of renewable and low-carbon hydrogen will become essential to effectively and efficiently decarbonise the energy system. Hydrogen (H2) and its carbon derivatives are considered as key options for the decarbonisation of hard to decarbonize sectors such as transport and the industry, or for providing energy storage solutions and flexibility to the energy system. These new carbon-free carriers will rely mostly on carbon-free electricity, including "green" hydrogen obtained from renewables. Hydrogen can gradually replace natural gas as a fuel for heating purposes (with fuel cells or H_2 boilers), for transport (with fuel cells), for power generation (with fuel cells and hydrogen turbines), and as feedstock for industrial applications (e.g. steel industry, refineries, fertilisers). In a power system largely based on variable renewable sources, hydrogen could be produced at times of low electricity demand to provide additional flexibility. According to the LTS, the whole consumption of hydrogen would increase from almost 0 Mtoe in 2015, to some 77 Mtoe in 2050 (1.5TECH).

Gas infrastructure

Gas infrastructure is a pivotal component of the current EU energy system, transporting over a third of the EU's final energy consumption, being the most important form of energy storage, and responding for energy imports representing over 8% of the EU final energy consumption. While gas demand levels (and domestic EU natural gas production) are expected to decrease, there is much uncertainty on how much, and also on the development of renewable and low-carbon gas sources. Gas networks could play a similar role (proportionally) by 2050, transporting over a third of all energy consumed in the EU, while the storage of gaseous fuels could maintain it's current importance. As for electricity networks, gas infrastructure face significant challenges: besides the expected decrease in demand (especially after 2030), it will need to integrate hydrogen and methane gases produced by renewable or low-carbon technologies which will need to achieve cost reductions and maximise the use of energy resources. The repurposing of methane infrastructure to import, transport and store hydrogen may transform large parts of present gas infrastructure and require significant investments as well as technology developments.

Electricity networks

Electricity networks are a central component of the energy system, transporting around 22% of the final energy consumed in the EU. Their importance is poised to grow in the future as electrification is a highly important strategy for the decarbonisation of the EU energy system. Furthermore, increased interconnection will allow to further integrate renewable energy sources, providing flexibility to the energy system, and also facilitating the transformation of hard-to-decarbonise sectors which are not easily electrified, such as high-temperature industrial processes. However, there is a number of challenges to the future development of electricity networks, including the exact levels of electrification, the significant investment needs and the need for further improving market efficiency and price signals.[20]

[18] IEA (2019), The Role of Gas in Today's Energy Transitions. Available at: https://webstore.iea.org/the-role-of-gas-in-todays-energy-transitions

[19] IEA (2020) The Role of Gas. Available at:
https://webstore.iea.org/download/direct/2819?fileName=TheRoleofGas.pdf

[20] European Commission expert group on electricity interconnection targets (2020) Fourth report - Contribution of the Electricity Sector to Smart Sector Integration

Batteries for mobile / stationary applications / recharging stations / smart charging / V2G

While the current share of electric vehicles in the EU vehicle fleet is small, battery electric vehicles could grow to represent over a quarter of total final energy consumption in the EU transport sector by 2050, according to the Long-Term Strategy. In the Long-Term Strategy, in the 1.5TECH scenario reaching net zero by 2050, the share of battery electric and fuel cell drivetrains (passenger cars) would reach 96% in 2050 (around 80% for battery electric and 16% for fuel cells), while for less ambitious scenarios (80% GHG reduction by 2050), this share would be at least of 51% (in the H2 scenario, with 16% for fuel cells). There is a common consensus on the fact EVs will play an important role in decarbonising the passenger car segment.

Moreover, together stationary (front- and behind-the-meter) and mobile batteries will be one of the main flexibility resources for the energy system on the daily to weekly timeframes.[21] In the case of lithium-ion batteries (LIBs), the market has been growing annually at a rate of 26 % in capacity and 20% in value since 2010. In 2017, the total market size of LIBs was approximately 120 GWh or €24 billion. As for stationary energy storage, market penetration is also increasing but at much lower volume of 6.5 GWh in 2017.[22]

Hydro pump storage

Hydropower includes stations operating with large water quantities stored in artificial reservoirs behind dams called storage power plants, run-of-river projects utilising the real-time natural flow of water bodies, and pumped hydropower storage (PHS). Pumped-storage hydropower plants operate with two reservoirs - a lower and an upper one (producing like a conventional hydroelectric plant via water release; pumping the water from the lower reservoir to the upper one, consuming electrical energy from the grid). Therefore, components of the supply chain are more or less the same as hydropower.

With about 60 to 70% of the economically feasible hydropower potential used so far within Europe, there is still an untapped potential,[23] and the share of pumped hydro storage relative to total EU energy storage could grow by 2050, according to the Long-Term Strategy (representing ~48TWh out of the total storage of ~281TWh in 2050 in the 1.5TECH scenario[24]).

Fuel cells / HRFs

PEMFC technology is currently the most popular, having the higher power density and operating at relatively low temperatures compared to other FC types, which makes it ideal for the automotive sector (e.g. FC light duty vehicles, FC buses, heavy duty vehicles, trains, airplanes, ships)[25] and forklifts. SOFC are also employed for combined heat and power production, due to its higher efficiency, but its high operational temperature is disadvantageous for transport applications.
In the Long-Term Strategy, the use of hydrogen develops in industry, transport (mostly for heavy duty vehicles, which do not have the option of electrification unless covering only short distances) and, to a lower extent, in buildings (with heating equipment consuming hydrogen blended with gas). Large scale deployment takes place (up to some 80 Mtoe in 2050 in 1.5TECH) as soon as consuming technologies are available (i.e. fuel cell vehicles) and competitive (in final energy demand). Given the fact industrial applications are very particular and adapted to the specificities of the processes, it is difficult to consider mass market for each application. Hence, the end-use concerns only the use of fuel cells vehicles (and their related Hydrogen Refuelling Stations, HRFs).

Smart buildings and automation (incl. HVAC)

As recognised by the Long-Term Strategy, "digitalisation is shaping Europe's energy system transformation in enabling the shift towards a highly distributed, networked, and dynamic grid, which leads to the creation of technology-rich platforms such as integrated distributed energy resources and smart and connected buildings". Smart technologies in buildings are capable to optimising the

[21] Trinomics, Artelys and Enerdata (2020) Study on energy storage – Contribution to the security of the electricity supply in Europe

[22] EC (2017) Lithium-ion batteries for mobility and stationary applications. Available at: https://ec.europa.eu/jrc/sites/jrcsh/files/jrc114616_li-ion_batteries_two-pager_final.pdf

[23] https://hydropower-europe.eu/about-hydropower-europe/vision-of-the-forum/

[24] Communication COM/2018/773: A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, Figure 26, p. 79. Available at https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

[25] Materials dependency for dual-use technologies relevant to Europe's Defence sector (JRC, 2020) https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/materials-dependencies-dual-use-technologies-relevant-europes-defence-sector

building systems' operation, adapting to the needs of the occupants, ensuring optimal energy performance and providing flexibility to the entire energy system. Various policies ensure the use of smart applications, such as the Energy Performance of Buildings Directive (EPBD) which includes requirements for the installation of building automation and control systems (BACS) in all existing and new non-residential buildings under certain circumstances. The Third Energy Package requires EU Member States to deploy smart meters, which uptake is apparently encouraging, according to a recent report by the European Commission.[26]

Heat pumps

In the 1.5TECH scenario of the LTS, in the residential sector electricity share in heating grows from 14% in 2030 (5% in 2015) to 34% by 2050. The trend is stronger in services buildings, as electricity share for space heating grows from 29% (13% in 2015) in 2030 to reach 51% in 2050. In addition to space heating, heat pumps are more and more developing industrial applications, increasing the level of temperature, although Coefficients of Performance (COP) decrease with the temperature. Heat pumps cover a large spectrum of capacities from a few kW to several MW, to be used in applications ranging from households to industrial applications and district heating systems.
The yearly market demand and the related growth in unit sales in Europe is growing rapidly.

Digital technologies for the energy sector

The energy sector is critical to the economy and society as a whole[27], and digital technologies are increasing in importance for all energy supply, transport, storage and consumption technologies. While the energy sector has historically adopted digital technologies early on, digital technologies and components such as energy management systems, smart meters and sensors are being increasingly deployed across the energy sector, replacing analogue solutions. Energy technologies enabled by digital solutions, such as autonomous electric vehicles, smart buildings or distributed energy generation are poised to revolutionise the energy sector. Digitalisation is required for integrated energy systems and for many related new market elements, such as shorter-term energy markets, increased participation of demand response and aggregator business models. Moreover, digital technologies themselves consume energy, and data networks and centres represent today around 2% of electricity demand – although future trends are uncertain, and depend on the level of deployment and energy efficiency gains made. [28]

1.2. High-level assessment of vulnerabilities

Main findings of section 1.2

- The raw and processed materials stage of the supply chains is the most vulnerable stage
    - 26 raw materials of the 50[29] raw materials in total listed in the 2020 Critical Raw Materials List are employed in various strategic energy technology supply chains;
    - A number of other raw materials are important to the supply chains analysed but were not considered critical in the 2020 Critical Raw Materials List;
    - Processed materials appear to be less vulnerable as compared to raw materials. However, materials that today might not constitute a vulnerability could become subject to dependencies and availability concerns, depending on future global supply and demand developments.
- Manufacturing and assembly is the second most vulnerable stage across technologies
    - While EU companies are important global players in certain supply chains, the EU is highly dependent on imports of multiple or a few critical elements for other supply chains;

[26] COM/2014/0356 final. (23 July 2020). REPORT FROM THE COMMISSION Benchmarking smart metering deployment in the EU-27 with a focus on electricity. Available from https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1403084595595&uri=COM:2014:356:FIN

[27] Energy Expert Cybersecurity Platform (2017) Cybersecurity in the Energy Sector - Recommendations for the European Commission on a European Strategic Framework and Potential Future Legislative Acts for the Energy Sector

[28] IEA (2017) Digitalization & energy; European Commission - EU-wide Cybersecurity legislation: Report on the implementation of the EU rules in the energy sector

[29] In the 2020 CRM List Light Rare Earth Elements (LREEs) (made up of 8 elements), Heavy Rare Earth Elements (HREEs) (9 elements) and Platinum Group Metals (PGMs) (6 elements) are grouped together and thus reports 30 elements where in reality it is made up of 50 periodic table elements. We decompose the groups given that not all elements in each of these groups is relevant to the analysis.

- This includes solar panels, Li-Ion batteries, printed circuit boards, semiconductors[30] and nuclear-grade elements for nuclear power plants; permanent magnets for wind turbines; and previously HFC stack assembly.

- The O&M stage exhibits vulnerabilities for a number of technologies (wind, nuclear fission, electricity networks, gas infrastructures and digital technologies). This relates especially to cyber-security concerns;
- In the construction and installation issues were identified when large-scale planning and investments are required, such as for nuclear and hydro power and pumped storage.
- For incipient technologies, such as hydrogen fuel cells and lithium-ion batteries there may be less data on vulnerabilities especially at the manufacturing and upstream stages given the early stage of development.

The high-level assessment of vulnerabilities per element in the supply chains was based on the criteria listed in the table below, together with information/recommendations provided by relevant stakeholders throughout interviews as well as desk research and inputs from the questionnaire.

Table 1-8 List of criteria and metrics to assess supply chain elements vulnerability

Criteria	Proposed metric
Import dependency	- Import share - Number of importers/sources
Extent of know-how/specialisation in Europe	Using EU patents as proxy / other
Market concentration	Number of manufacturers/suppliers
Ease of substitutability	Based on evidence from stakeholder interviews[31]
Price stability of elements in the supply chain	Historic price trends

We used expert judgment to assess the vulnerability level per criteria to each of the elements in the supply chain stages. Considering the indicators and other qualitative aspects, including the feedback from stakeholders, the vulnerability of the supply chains was defined according to the number of vulnerable elements and their vulnerability level. Finally, supply chains which are considered to be of strategic importance and to have vulnerable elements were defined as critical.

1.2.1. Analysis of vulnerable elements per supply chain stage

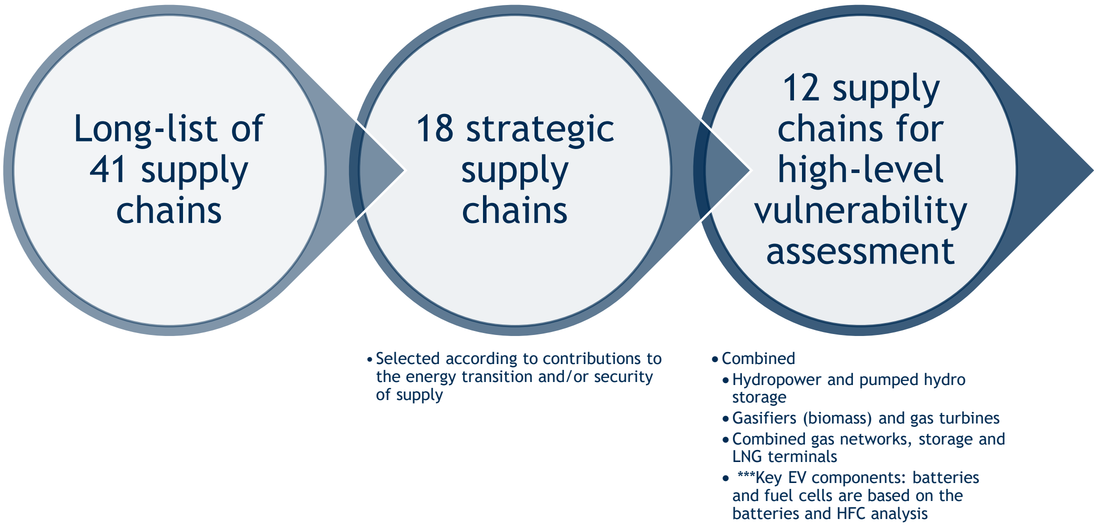
A high-level analysis of the supply chain technologies identified as strategic has been carried out as part of section 1.2. A summary of the supply chains assessed as well as key findings can be found in section 0 and a full analysis of each supply chain is included in Annex B. This section identifies and discusses vulnerable elements, organised per supply chain stage.

The vulnerability analysis is conducted jointly (i.e. some supply chains of section 1.1 are assessed together) for the following highly strategic supply chains (as illustrated in Figure 1-4):

- Batteries & electric vehicles ➔ batteries;
- Electrolytic hydrogen & fuel cells/hydrogen refuelling stations (HRS) ➔ hydrogen production, storage, and end-use (incl. partly FCEV);
- Hydropower & pumped hydro storage ➔ hydropower and PHS;
- Biomass – gaseous fuels & OCGT / CCGT (gas turbines) ➔ biomass gasifiers and gas turbines;
- Gas networks, liquefied gas terminals and gaseous fuels storage ➔ Gas infrastructure.

[30] This includes all types of finished semiconductor components employed in e.g. consumer, industrial, aerospace, and automotive electronics, covering from large power transistors to microprocessors and small semiconductor components employed in electronics boards.
[31] JRC (2016 report on substitution of Critical Raw Materials in low-carbon tech and DG RTD Energy Technology Dependence will provide guidance.

Figure 1-4 Supply chain analysis process until the high-level vulnerability assessment



Regarding the combination of technologies within the 'gas infrastructure' supply chain, natural gas production is considered strategic in section 1.1 due to its current contributions to the EU energy supply, amounting to almost 10% of the total final energy consumption. However, its strategic importance is due to decrease in the long-term given due to the reduction in EU production and consumption. Hence, vulnerabilities related to the impacts of the supply chain on the O&M of natural gas production, while impacts to the development of new natural gas fields will be very limited. For this reason, natural gas production technology supply chains are not analysed further. The analysis focuses rather on gas infrastructure supply chains (which combine network, LNG and storage technology supply chain for methane and hydrogen gases) and hydrogen production (as part of the H2 production / storage / use supply chain). Nonetheless, gas networks and storage share an important number of elements with natural gas production, and thus increasing the resilience of gas infrastructure will also have positive effects to natural gas production supply chains.

Table 1-9 provides a high-level overview of the supply chain stages (building blocks) with highest vulnerability per technology. Stages coloured in red indicate presence of a few vulnerable elements within the supply chain stage or of single-elements deemed to impart high vulnerability to the supply chain stage and/or full-value chain, those in yellow indicate that one or a couple of elements within the building blocks are vulnerable, finally, the green colour indicates that no major concerns have been identified.

Table 1-9 Summary of vulnerable elements per technology supply chain

	Raw & Processed Materials	Manufact. & Assembly	Transport	Construction & Installation	O&M	Decomm. & Circularity
Wind energy – onshore/offshore						
Solar PV						
Hydropower & pumped hydro storage						
Nuclear fission						
Biomass gasifiers and gas turbines						
Hydrogen production, storage & end-use (incl. for FCEVs)						
Gas infrastructure						
Electricity networks						
Batteries (incl. for EVs)						
Smart buildings						
Heat pumps						
Digital technologies						

Legend:
orange – supply chain stage with a few vulnerable elements / with high risk vulnerabilities;
yellow - supply chain stage with one to a couple of elements identified as vulnerable;
green – supply chain stage without vulnerable elements.

The **raw and processed materials** stage of the supply chains is the most vulnerable stage for most technologies analysed. Only in the case of gas infrastructure this stage of the supply chain is not considered vulnerable. In the case of hydropower, only a couple of points of concern have been identified (copper, concrete, steel, fibre-reinforced composites). For the remaining technologies, the first stage of the supply chains is characterised by important vulnerabilities. The critical raw materials for the strategic supply chains which are listed also in the 2020 Critical Raw Materials List are aluminium, boron, chromium, cobalt, gallium, indium, iron, lithium, natural graphite, palladium, platinum, rhodium, ruthenium and titanium. A number of other raw materials are important to the supply chains analysed but were not considered critical in the 2020 Critical Raw Materials List. An analysis of the commonalities in raw materials and processed materials dependencies between the technologies of interest is presented in Figure 1-5 and Figure 1-6 respectively.

Manufacturing and assembly is the second most vulnerable stage across technologies. While EU companies are important global players in certain supply chains such as wind, hydropower & pumped hydro or gas turbines, the EU is highly dependent on imports of multiple or a few critical elements for other supply chains. In the case of, for example, solar PV and batteries, the EU does not currently have sufficient manufacturing capabilities and it relies on imports from third countries. Regarding fuels cells and hydrogen technologies, the manufacturing of components is not of concern, however, the assembly of fuel cell stacks and systems appears to be critical, although, according to Hydrogen Europe, this is evolving fast with the recent industrial developments across EU and is not anymore a concern. The EU is a leader in many elements for smart buildings and digital technologies, but has a high reliance on imports of printed circuit boards, semiconductors and microprocess from Asian countries, as well as a lower presence in the home energy management software market compared to US companies. The nuclear fission supply chain arises from difficulties in certifying supplier for a wide range of nuclear-grade structures, systems and components.

The **O&M stage** exhibits vulnerabilities for a number of technologies (wind, solar PV, nuclear fission, electricity networks, gas infrastructures and digital technologies). In the case of smart buildings concerns are based on vulnerabilities to cyber-attacks which are more pronounced due to, among other elements, the high level of automation. This is also the case for digital technologies. In the case of nuclear fission, O&M vulnerabilities stem also from the high-quality standards that are required and the difficulty sourcing certain systems and components that fulfil these high standards.

For technologies such as hydro power and pumped hydro, nuclear fission and solar PV and wind, construction projects require large-scale planning and investments some vulnerabilities have been identified in the **construction and installation** stage of the supply chain.

No vulnerabilities were reported for the **decommissioning** and circularity supply chain stage. It is important to note, that this stage of the SC was not analysed in detail, given that, as explained in Annex A, it is not expected to be of major concern for the energy transition or security of supply. Based on the information gathered for this study, the logistics of transport in the supply chain do not constitute an inherent vulnerability in the supply chain. Nonetheless, based on stakeholder interviews, the wind industry indicated that investments in the transport infrastructure such as ports is an important element for consideration to ensure the well-functioning of transport and distribution stage of the supply chain. Furthermore, considerations on problems associated with transport and distribution associated with COVID-19 measures are listed and discussed in section 2.1.

Raw materials stage

Figure 1-5 gives an overview of the vulnerable raw materials for the technology supply chains. It presents the vulnerability of each raw material as follows:

- **Bold**: Raw materials highlighted in bold in the first column are on the 2020 Fourth Critical Raw Materials List developed by the European Commission;[32]
- Green: Elements marked as green refer to raw materials that are used in each technology supply chain. Cells in grey do not necessarily indicate vulnerability of these elements;
- Light orange: Materials classified as critical by the EC and required in the strategic technologies supply chains are coded with light orange;
- Dark orange: Raw materials coded with dark orange indicate materials where dependencies or other vulnerabilities have been identified for the supply chains of energy technologies. These materials may be listed or not in the 2020 Critical Raw Materials List.

The vulnerability assessment conducted based on the methodology developed for this study distinguished between elements that are vulnerable (dark orange) and not (green). The additional shade, in light orange, has been added to emphasise that materials that may currently not constitute a vulnerability for a given chain (should be green) might be subject to competition considerations given that the material is considered critical from the economy-wide perspective. For example, a recent JRC study identified that the wind energy and traction motors (including those used for robotics and drones) compete for various rare earth elements (required in permanent magnets in the wind industry).[33] Furthermore, it is important to note that the methodology for defining criticality in this study differs from the one used by the JRC for identifying the EU critical raw materials, thus materials classified as vulnerable (dark orange) for a given technology supply chain might not be listed under the 2020 Critical Raw Materials list compiled by the JRC. The vulnerability analysis is made per technology supply chain based on considerations described in the methodology section and additional information provided through stakeholder inputs. This is also the reason why a certain element might be classified as vulnerable for one technology but not another.

Overall, the energy sector requires **more than 40 different raw materials** ranging from very high to low supply risk. Given their level of complexity and broad scope the smart buildings automation and digital technologies supply chains have the highest number of vulnerable raw materials. Furthermore, given the level of digitalisation required for smart buildings automation the two supply

[32] European Commission. (2020). Critical Raw Material List 2020. Available at: https://rmis.jrc.ec.europa.eu/?page=crm-list-2020-e294f6
[33] JRC. (2020). Critical Raw Materials for Strategic Technologies and Sectors in the EU – A Foresight Study.

chains have many raw materials in common. Silicon represents a vulnerable material for all six technology supply chains where dependence on this material has been identified. In contrast, copper is also widely used across technologies (in seven of the considered supply chains), as well as iron an aluminium, but are not considered vulnerable for most of those technologies. In the case of wind energy, copper has been assessed as a vulnerable element based on concerns of future availability reported in the analysis for the Germany wind energy market. [34] In the case of nuclear fission, chromium, nickel and zinc are important raw materials. However, the EU has an import reliance ratio of around or over 60% for all three elements. Moreover, for these materials the foreign supply market is highly concentrated, with again the market concentration ratio of the top four suppliers (CR4) being over 60%. Aluminium, boron, cobalt, lithium, magnesium and natural graphite elements that exhibit vulnerabilities across four to six supply chains. Several other raw materials are common for at least three supply chain technologies.

[34] Shammugam, S. et al. (2019). Raw metal needs and supply risks for the development of wind energy in Germany until 2050

Figure 1-5 Summary of vulnerabilities by energy technology and raw materials

	Wind	Solar PV	Hydropower and pumped storage	Hydrogen fuel cells & storage	Nuclear fission	Biomass gasifiers and gas turbines	Gas infrastructure	Electricity Networks	Batteries (incl. for EVs)	Smart buildings	Heat Pumps	Digital technologies
Raw materials												
Aluminium												
Arsenic												
Boron												
Bismuth												
Cadmium												
Cerium (LREE)												
Chromium												
Cobalt												
Copper												
Dysprosium (HREE)												
Europium (HREE)												
Fluorspar												
Gallium												
Germanium												
Gadolinium (HREE)												
Gold												
Indium												
Iridium (PGM)												
Iron												
Lanthanum												
Lead												
Lithium												
Manganese												
Magnesium												
Molybdenum												
Natural graphite												
Neodymium (LREE)												
Nickel												
Niobium												
Palladium (PGM)												
Phosphorous												
Platinum (PGM)												
Rhodium (PGM)												
Ruthenium (PGM)												
Selenium												
Silicon												
Silver												
Tellurium												
Terbium (HREE)												
Tin												
Titanium												
Tungsten												
Vanadium												
Yttrium (HREE)												
Zinc												

Legend:
bold *– critical raw materials (CRMs) based on EC list for 2020;*
green – raw materials relevant/used in a technology (does not necessarily indicate problems);
light orange – CRM required in the supply chains, but no technology-specific vulnerability identified;
dark orange – raw materials relevant/used in a technology and identified as vulnerable.
HREE – Heavy Rare Earth Element
LREE – Light Rare Earth Element
PGM – Platinum Group Metals

Processed materials stage

Figure 1-6 lists the processed materials identified as vulnerable across all the technology supply chains analyses. The figure lists **29 different types of material of relevance**. Compared with the raw materials, there are less points of synergies across supply chains. Nonetheless processed materials such as cement, carbon and glass fibre, stainless and grain-oriented steel are relevant across several technologies albeit to different extent. In other cases, the processed materials are much more specialised and thus relevant only for specific supply chains. Furthermore, processed materials such as metal alloys are based on raw materials, many of which are subject to vulnerabilities as discussed above. Although the processed materials across supply chains may differ, the characteristics that make then vulnerable are often similar to those of raw materials and can be observed across the different technologies. These include high import reliance, high market concentration, difficulties with diversification or substitution or a combination of all factors. In addition, for several supply chains considerations on future material demand are of relevance. Compared with the raw materials, fewer vulnerabilities are observed for the processed materials. The analysis shows that electric networks exhibit vulnerability in relation to grain-oriented steel. Grain-oriented electrical steel (GOES) is a material that is considered relevant and potentially vulnerable in the case of both electrical networks and wind energy technologies. The material is used in the manufacturing of transformers used in the electricity transmission and distribution as well as in wind turbines. The EU supply of high-permeability domain-refined GOES is currently insufficient to satisfy the EU demand for the product, which is one of the main solutions available to meet the EU ecodesign requirements for transformers. EU electrical steel producers have faced financial difficulties since the late 2000s financial crisis decreased global demand for the product, with the recent closure of Orb Electrical Steel in the UK. Global competition has prompted the EU to introduce anti-dumping measures for electrical steel in 2015. The supporting investigation confirmed that the introduction of ecodesign requirements increased demand for high-permeability GOES.[35]

Materials that today might not constitute a vulnerability could become subject to availability concerned based on forecasts of market growth and future demand.[36] Such problems could be exacerbated by demand from other sectors for the same, limited materials. In order to anticipate such problems, regular assessment updates should be made.

Although **compressed storage for hydrogen** appears to have many players, few of them are producing tanks in Europe (hydrogen compressed tank supply has some strong Asian and North American players[37], with Japan as main **carbon fibre** supplier), which has been considered as a weakness in the supply chain. However, given the fact the fuel cells market is now developing, carbon fibre manufacturers are investing to increase their EU capacity, which is also used in other critical energy chains. In addition, Europe has a base of high-quality balance of plant component suppliers which would be well positioned to supply a growing market. Current tanks are very similar between suppliers - a cheaper, lighter or otherwise better-performing tank developed elsewhere could change markets rapidly.

An initiative to restrict and ultimately ban the manufacture and use of all PFAs ("per and polyfluorinated alkyl substances"), including fluoropolymers, in Europe has been launched mid of 2020. This initiative is called **the EU PFAS Strategy**[38]. The unintended impact of an insufficiently considered ban on all PFAs would be to severely inhibit the manufacture and use of PEM fuel cells and electrolysers, because at their heart they depend on gas impermeable proton conducting fluoropolymer membranes (**PFSA**, or perfluoro-sulfonated acids). While there are currently no alternatives. This may increase the vulnerability for the supply of polymer electrolyte membranes (PEM).

[35] Commission Implementing Regulation (EU) 2015/1953 imposing a definitive anti-dumping duty on imports of certain grain-oriented flat-rolled products of silicon-electrical steel originating in the People's Republic of China, Japan, the Republic of Korea, the Russian Federation and the United States of America.
[36] See for example, JRC (2020) Critical Raw Materials for Strategic Technologies and Sectors in the EU – A foresight Study, for forecasts on future material demand.
[37] E4tech for Fuel Cells and Hydrogen 2 Joint Undertaking. (2019). Available at: https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf
[38] European Commission. (2020). SWD(2020) 249 final. Poly- and perfluoroalkyl substances (PFAS). Available at: https://ec.europa.eu/environment/pdf/chemicals/2020/10/SWD_PFAS.pdf

Figure 1-6 Summary of vulnerabilities by energy technology and processed materials

	Wind	Solar PV	Hydropower and pumped storage	Nuclear fission	Gas turbines (CCGT)	Hydrogen fuel cells & hydrogen storage	Gas Infrastructure	Electricity Networks	Batteries (incl. for EVs)	Smart buildings	Heat Pumps	Digital technologies
Processed materials												
Boron nitride powder												
Carbon Cloth / paper												
Carbon Fibre Composite												
Ceramics						YSZ[39]						
Composite polymers												
Cement												
Dicumyl peroxide												
Ethylene propylene rubber												
Fibre glass												
Glass												
Grain-oriented steel												
Graphene												
High-density propylene												
Low-density polyethylene												
Metal hydrides												
Metal alloys												
Mineral oil												
Nanomaterials and carbon nanotubes						CNT[40]						
Nickel-chromium - iron alloys												
Nitrile												
Odorants												
Plastic												
Polyamide ultramid												
Polymer electrolyte						PFSA[41]						
Porcelain												
Porous carbon material												
Scrap and flake mica												
Stainless Steel												

Legend:
green – processed materials relevant/used in a technology (does not necessarily indicate problems);
dark orange – processed materials relevant/used in a technology and identified as vulnerable.

[39] Ceramic Yttria Stabilised Zirconia
[40] Carbon Nanotubes
[41] Current polymer electrolyte membranes (PEMs) for fuel cells are mostly based on perfluoro-sulfonated acids (PFSA)

Manufacturing and assembly stage

In the manufacturing stage of the supply chain few common elements can be identified. Table 1-10 provides an overview of the key vulnerabilities identified at this stage per strategic energy technology.

For technologies such as batteries and solar PV, manufacturing in Europe is still limited. In the case of **solar PV**, China has a quasi-monopolistic role at the components stage. The EU provides around 1% of the global silicon-based PV assemblies. Currently, the EU provides less than 1% of **Li-Ion batteries**. China, together with Africa and Latin America, provides 74% of all Li-Ion batteries raw materials. China also supplies 66% of finished Li- Ion batteries.[42] Importantly, although the analysis of manufacturing and assembly was grouped under the same supply chain stage, these two do not always exhibit the same characteristics and vulnerabilities.

In the case of the **hydrogen production, storage and end-use** supply chain the manufacturing of components is not of concern, however, the assembly of fuel cell stacks and systems appeared to be critical, although this is evolving fast with the recent industrial developments across the EU.

For the **nuclear fission** technology supply chain bottlenecks have been identified for modern nuclear reactors (Gen III+) where forging of the pressure vessel requires equipment which is scarce worldwide. With the reduced construction rate for nuclear energy plants in Europe, challenges related to capability, i.e. the sufficient availability of qualified personnel to design, build and operate the plants, including in the products and services supply chain have been observed.

In the case of **smart buildings**, the EU is leader in the manufacturing of certain components but is a net importer of light fixtures and HVAC equipment. The EU is a net importer of **digital technologies**, with a trade deficit in 2017 of 23 billion €, mainly due to imports from China. More specifically, the EU is highly dependent on East Asian countries for the supply of printed circuit boards (EU has 10% of global production), semiconductors and microprocessors (EU has 9% of global production), as well as from Asian and North American suppliers for servers and data storage equipment and from North American suppliers for home energy management system. Overall, the EU has a share around 4% of the global telecommunications equipment.[43] However, the EU is a strong player in other digital technology elements which are significant for energy technologies, especially industrial electronics (with a 20% share of the global production and being a leading player especially in factory automation, power applications and transportation), sensoring and metering, and software for virtual power plants, management of distributed energy resources and advanced energy distribution management systems.

In the case of electricity networks and gas infrastructure, overall, the manufacturing stage of the supply chain was not found to be highly vulnerable. In both cases interviews with representative stakeholders did not indicate major concerns with regards to this stage. For example, in the case of **electricity networks**, the main European manufacturers of transformers (Siemens, ABB Group, CG Power System, and Schneider Electric) are important global players. In the case of forward-looking considerations related to, for example, the expansion of the offshore grid, assessments indicate that European cable manufacturers would have sufficient capacity to match the forecasted demand for submarine cables considering the ENTSO-E's TYDNP 2018. One element which could constitute an issue in the future pertains to the development and deployment of multivendor multiterminal HVDC systems, which would be necessary for the development of an offshore grid and where China has in recent years become the leader regarding projects in the area and the experience developed.[44] For **gas infrastructures** no issues related to import reliance of components were reported, although filters/scrubbers and floating storage and regasification units (FSRUs) for liquefied gas may be a concern. However, input from stakeholders indicate that low quotas for large diameter pipes may lead to longer waiting periods for deliveries.

The market share of **hydropower (and pumped hydro storage)** for the 2013-2017 period was led worldwide by Asian companies (45.9% for China, 0.7% India and 1.6% Japan), then by European companies with 32.4%, and then by America with 17.2%. The catalyst for the strong Hydro-Turbine

[42] JRC. (2020). Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study. Available at: https://ec.europa.eu/docsroom/documents/42881/attachments/1/translations/en/renditions/native
[43] DECISION for DG CONNECT. (2020). Study on the Electronics Ecosystem. Available at: http://www.decision.eu/wp-content/uploads/2020/02/DECISION_Study_Electronics_Ecosystem.pdf
[44] DG ENER. (2020). Workshop: Horizon 2050 power system and the role of HVDC technologies in a highly decentralised RES generation.

Generators (HT&G) market during the same period was China representing about 58.7% of the total installed capacity, followed by India (4.4%), Brazil (4.2%), Ethiopia (3.2%) and Laos (2.8%). Outside China, the EU-based companies delivered 56.2% of the total orders in terms of capacity (2013-2017).[45] Europe has a strong and resilient manufacturing activity and is a major exporter of technologies out of Europe.

Based on stakeholder input, the assessment of the manufacturing stage of **gas turbine** technologies found that heavy duty turbine blades and vanes castings are mostly supplied by providers outside of Europe and could represent a potential fragility for the European gas turbine supply chain. However, this fragility did not manifest itself in the form of major disruptions during the COVID-19 pandemic. No additional major concerns were reported, with 5 (4 EU27 + one from UK) out of the 10 top manufacturers having their headquarters in Europe.

Finally, the European **wind manufacturing industry** is well developed, and the European manufacturers exhibit overcapacities in all key wind turbine components, when compared to the present and future European demand forecasts.

Table 1-10 Summary of key manufacturing and assembly considerations to assess vulnerabilities per strategic energy technology

Technology	Manufacturing and assembly vulnerabilities
Wind	European manufacturers of wind turbines and their components are well positioned globally. The EU plays a major role only in the assembly stage, where its share is above 50%.
	The vulnerability of permanent magnets which are often imported from CN or JP stems from their raw material requirements (Nd, Dy).
Solar PV	The EU provides around 1% of the global silicon-based PV assemblies.
Hydropower and pumped storage	EU manufacturers can be considered having a leading role. The EU is the world leader in hydropower technology (included pumped hydro), exporting its technologies all over the world.
Nuclear fission	Limited number of certified suppliers for high safety class components.
	Particularly vulnerable components are: steam generator, reactor pressure vessel/head, control rods, rod cluster control assembly, valves, heat transfer tubes and bundles etc.
Biomass gasifiers and gas turbines	Heavy duty turbine blades and vanes casting supplies are mostly located outside of Europe and could represent a potential fragility for the European gas turbine supply chain.
	4 out of the top 10 gas turbine manufacturers are headquartered in the EU27 (Ansaldo Energia, Siemens Energy, MAN Energy Solutions, OPRA Turbines) an additional one is based in the UK (Centrax Gas Turbines).
	Regarding the geographic distribution of demand for gas turbines, the main markets would be North America (a quarter of the demand in 2018-2027), Europe (over 17%) and Asia (around 16%)
Hydrogen fuel cells and hydrogen storage	Europe has the capacity to produce all major components used in FC and electrolysers, namely Bipolar Plates, catalysts, Gas Diffusion Layers, membranes and hydrogen vessels
	Europe is one of the leaders in today's global all three main technologies of electrolysis industry with the major manufacturers producing in France, Germany, UK, Norway and Belgium
	Europe is globally well positioned all along the PEM electrolyser supply chain, however, the electrolyser specific supply chain is in general less developed compared with PEM fuel cells.
	The formal supply risk for the assembled FCs is no longer a concern as the industry is developing its EU capacities, although there is currently no evidence (close monitoring would then be required, as developed under 3.2.4)
Gas infrastructure	No major issues related to import reliance of components, although filters/scrubbers and floating storage and regasification units (FSRUs) for liquefied gas may be a concern.
	Suppliers point at low large diameter pipes import, quotas which result in longer waiting periods for deliveries (as suppliers wants to sell their products within given quotas, which guarantees lower custom tariffs, they prolong delivery period to e.g. opening the window for new import quotas).

[45] McCoy power reports. (2018). Hydro Turbines and generators 12M'17 Report. Available at: https://www.mccoypower.net/products

Technology	Manufacturing and assembly vulnerabilities
Electricity networks	In terms of import dependency no major concerns were identified
	In terms of value transformer production was 13.6 times higher than imports. This indicates that, for larger transformers, the EU production is larger than imports.
	The main European manufacturers of transformers (Siemens, ABB Group, CG Power System, and Schneider Electric) are important global players.
	The EU is a net exporter of ceramic and glass insulators and related components
	No specific bottlenecks identified for voltage source converters
	China is a leader in the development and deployment of multiterminal HVDC systems, which would be necessary for the development of an offshore grid
	In 2019 the industry association Europacable assessed that the manufacturing capacity of European cable manufacturers would be sufficient to match the forecasted demand for submarine cables considering the ENTSO-E's TYDNP 2018.
Batteries (including for EVs)	Currently, the EU provides less than 1% of Li-batteries.
Smart buildings	The market for energy management and related software is in general highly concentrated, with European players having a strong position for many software categories.
	The US is a leader in home energy management software, with only Schneider Electric (FR) being a main supplier based in Europe. However, there is a large number of new entrants in the market – also globally.
Heat pumps	The European HP manufacturing sector comprises major world known names in heating, but also global and major European refrigeration and air-conditioning players
Digital technologies	The EU is a net importer of digital technologies, with a trade deficit in 2017 of 23 billion €. The EU is highly dependent on East Asian countries for the supply of printed circuit boards, semiconductors and microprocessors as well as from Asian and North American suppliers for servers and data storage equipment and from North American suppliers for home energy management system.
	The EU is a strong player in digital technology elements, especially industrial electronics, sensoring and metering, and software for virtual power plants, management of distributed energy resources and advanced energy distribution management systems.

Legend:
red – supply chain stage with a few elements identified as vulnerable / vulnerabilities deemed to be high risk,
yellow - supply chain stage with one to a couple of elements identified as vulnerable;
green – supply chain stage without vulnerable elements.

The technology supply chains identified as vulnerable at the manufacturing and assembly stage (Solar PV, Batteries and Digital technologies) are expected to play an increasingly important role in the future, decarbonised energy system (see Table 1-2 and Table 1-6). Activities to support strengthening manufacturing capacity are already taking place. In the case of Solar PV, the Solar Manufacturing Accelerator launched by SolarPower Europe aims at accelerating the deployment of solar PV manufacturing projects and the re-industrialisation of solar PV in Europe.[46] Equipment manufacturers are still present in Europe, and especially in Germany, with strong industrial knowledge. The EU's Strategic Action Plan on Batteries[47] lies down a comprehensive strategy to enhance the EU battery value chain stages including manufacturing. In the case of digital technologies, the large variety of components constituting the supply chain, requires that additional care be taken when formulating conclusions. Whereas EU's position in the production of embedded electronics, sensor system and power electronics is good, the EU produces only 10% of the world's electronic boards and 9% of its semiconductors and microprocessors. In December 2020, 19 Member States signed a declaration to commit to working together to strengthen the EU's electronic and

[46]SolarPower Europe. (n.d.). Solar Manufacturing Accelerator – Accelerating the deployment of solar PV manufacturing projects in Europe. Available at: https://www.solarpowereurope.org/campaigns/manufacturing-accelerator/
[47] European Commission. (2019). EU Strategic Action Plan on Batteries. Available at: https://ec.europa.eu/info/sites/default/files/report-building-strategic-battery-value-chain-april2019_en.pdf

embedded systems value chain and leading-edge manufacturing capacity in order to increase Europe's capabilities in processors and semiconductor technologies.[48]

Construction and installation stage

The construction and installation stage of the supply chain is resilient for most supply chains. This assessment refers to the analysis of vulnerabilities in the absence of exacerbating, external factors such as the ones which are analysed under chapter 2. In the process of interviewing stakeholder for this part of the analysis, we did learn about several disruptions and problems in the construction and installation stage resulting from COVID-19, these are summarised and discussed further under chapter 2. In the case of the wind supply chain, the biggest vulnerability in this stage of the supply chain pertains to the lengthy and often varying permitting procedures for onshore and offshore windfarms in different Member States. The different national rules, and difficulties associated with knowing and understanding them can lead investors to decide for investing in projects outside of Europe. Difficulties associated with permitting can also lead to increased project costs, reluctance to provide financing or lending due to associated risks of permitting and limited use of the latest technology available (If the permitting process takes between two or three years, the turbine model proposed becomes obsolete considering the pace for technology development within the sector). Furthermore, in the case of offshore wind, the availability of wind turbine installation vessels which are limited in number and expensive could constitute an additional bottleneck especially in the future (offshore wind is growing to such an extent that suppliers of vessels might not keep up). Due to the high risk and specific know-how required associated with the construction of nuclear power plants some vulnerabilities have also been identified for this technology. Finally, the construction of large-scale hydro-power plants is also subject to vulnerabilities based on uncertainties associated with large amount of capital investments, complex structures and extensive construction periods. Obtaining a permit for a hydro power plant may take years, up to a decade, which is prolonging the delivery, and possibly discarding the potential additional capacity, by discouraging developers.

Operation and maintenance stage

Several activities fall under the O&M stage which broadly can be divided into corrective and preventive (scheduled and condition-based) operation and maintenance activities. However, using the new remote services, operators can switch from corrective and preventive maintenance programs to proactive O&M strategies. In this stage of the supply chain, vulnerabilities were identified in the case of the majority of technologies analysed, these are shortly discussed in this section and further detailed in section 1.2.2 and Annex B.

In the case of nuclear energy, it is difficult to find suppliers in the EU willing to face the costs of obtaining certificates and keeping a costly QA program when there is no certainty on future demand, as obtaining and maintaining a certification is costly and only worthwhile for the supplier if there is reasonable expectation of demand for its products and services. This applies especially to suppliers for nuclear-grade systems, structures and components, including all in the nuclear island. This includes for example parts for the control and fuel rods, primary water circuit and many other components. This is a concern shared generally by the operators in EU Member States which have nuclear power plants. O&M issues in offshore wind have been described in the literature and they consist primarily of concerns around inflexibility of planning for O&M, lack of coordinated planned services at the wind farms, lack of common understanding of how O&M should be managed and the short-term nature of O&M contracts.[49] These concerns, can be partly attributed, to the industry being relatively young and lacking experience. In the case of gas infrastructure, risk assessments usually focus on gas commodity supply risks focused on pipelines. Dependence on spare parts to address planned and unplanned maintenance requirements could become a potential vulnerability given the supply chain for the main components such as pipelines, compressor parts and other elements (valves, gaskets) is integrated.

For the majority of technology supply chains, the increased digitalisation of the operation and maintenance also represents an increased concern on cybersecurity. This is the case of solar PV,

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[48] European Commission. (2020). Press Release: Member States join forces for a European initiative on processors and semiconductor technologies. Available at: https://ec.europa.eu/digital-single-market/en/news/member-states-join-forces-european-initiative-processors-and-semiconductor-technologies

[49] Baagøe-Engels, V. and Stentoft, J. (2016). Operations and maintenance issues in the offshore wind energy sector: An explorative study. International Journal of Energy Sector Management, 10(2), 245 - 265
Available at: http://dx.doi.org/10.1108/IJESM-04-2015-0012

wind, gas turbines, smart buildings automation and digital technologies, electricity networks and gas infrastructure. For electricity networks, cybersecurity of the electricity system is an important concern. As for the electricity system, gas network control systems could be compromised through ITC service providers, unintentional vulnerabilities or backdoors added in equipment during the design, manufacturing or shipping stages. In the case of solar PV, although, in general PV plants are in operation for at least 15 to 20 years and always keeping their cybersecurity measures up to date, the concerns are mostly around small and medium- sized PV arrays where the installers and operators may not be updated on the relevant security measures. Power plant controllers could also be vulnerable. Offshore wind parks as well as gas turbine maintenance services often require structured and secure remote monitoring of multiple turbines at multiple sites for analytics and optimization. However, direct internet access would render them vulnerable to cyber-attacks. Companies in the gas turbine manufacturing and O&M market are developing a number of solutions to address these threats. An example of a solution developed based on a data diode approach relies on tags to transfer information from turbines to remote monitoring web portal for O&M analytics.[50] Vulnerabilities to cyber attacks and mitigation measures are further considered under this study in section 2.2 and under chapter 3 (policy measures).

1.2.2. *Overview of supply chain* analyses per strategic technology

Based on the analysis described above to identify strategic technology supply chains a high-level assessment of these was undertaken. The full, high-level vulnerability analysis per supply chain technology can be found in Annex B. Below we provide a short summary of elements analysed and key findings.

Wind (onshore & offshore) supply chain

Wind turbines have become a mature and highly sophisticated electricity generation technology. Current developments are aimed at cost reductions and efficiency improvements to meet ambitious targets for reduction of the cost of electricity generated. The supply chain analysis encompasses the basic elements of the wind turbine: blades, the rotor hub, the rotor shaft, the nacelle, the rotor brake, the gearbox, the generator and controller, the tower and the transformer. Due to the commonalities between the critical dependencies for onshore and offshore wind, it is suggested the two technology variants be considered at the energy technology family level (wind energy).

In the raw material block of the supply chain the rare earth elements, neodymium and dysprosium, have been identified as being at risk due to high import dependency. Wind turbine manufacturers use **neodymium** (Nd) and **dysprosium** (Dy) for their permanent magnets. In the case of both rare-earth materials used for manufacturing **permanent magnets** (neodymium and dysprosium) the EU is fully reliant on non-EU suppliers which are heavily concentrated in a few countries with China being the dominant supplier in both cases. Difficulties to enter the market for new suppliers and the lack of suitable substitutes, in particular for neodymium, result in a high overall risk of these dependencies. Given that permanent magnets are dependent on critical raw materials by extension their production is subject to certain vulnerabilities (research of material substitutes is ongoing). A study on the raw material needs and supply risks for the development of wind energy in Germany until 2050 identifies dysprosium and **copper** as the most critical materials. Copper and dysprosium are substitutes; generators without permanent magnets (which contain Dy) contain in exchange more copper windings.[51] **Grain-oriented electrical steel** (GOES) is a crucial material in the wind industry used for the manufacturing of transformers as well as in wind turbines, for which the EU there is a high dependence on non-EU suppliers.

The European manufacturers account for ~35 % of the global wind turbine value chain. They are only superseded by manufacturers from China. The European wind industry has high manufacturing capabilities in components with a high value in wind turbine cost (e.g. towers, gearboxes and blades), and in components with synergies to other industrial sectors (generators, power converters and control systems). Furthermore, of the 10 biggest wind turbine manufacturers in the world, five of them are based in the EU. In addition, analysis by the EU's Joint Research Centre shows that the European manufacturers exhibit overcapacities in all key wind turbine components, when compared to the present and future European demand, at deployment rates between 12.1 and 22.7 GW/year.[52]

[50] OWL Cyber Defense. (2019). Gas turbine Support Vendor Enables Centralized Remote Operation and Maintenance Monitoring. Available at: https://owlcyberdefense.com/wp-content/uploads/2019/05/owlcyberdefense-use-case_gas-turbine-power-gen.pdf
[51] Shammugam et al. (2019). Raw metal needs and supply risks for the development of wind energy in Germany until 2050.
[52] JRC (2019), Wind Energy – Technology market report

In the offshore wind sector **wind turbine installation vessels** (WTIV) used for the installation of offshore wind turbines represent an important consideration in terms of costs and planning. Both their high cost (~ USD 335 million or USD 220,000/day) and limited availability (16 WTIV worldwide) make this an element in the supply chain that could impart vulnerability.

Data analytics, automation measures and predictive maintenance will become increasingly important for the efficient performance of O&M of both onshore and offshore wind. For offshore wind where the O&M costs are generally higher due to more expensive maintenance and logistics procedures and complications related to shortages of skilled workers, digitalisation and predictive maintenance are promising options. Digitalisation has and will continue to also an important role during the COVID-19 pandemic, allowing companies to maintain continuity of operations.

Table 1-11 Overall assessment for wind supply chain

Overall assessment for wind (on-shore and off-shore) supply chain	
Strengths	**Weaknesses**
The European wind industry has high manufacturing capabilities in components with a high value in wind turbine cost and in components with synergies to other industrial sectors. The EU plays a major role in the assembly stage with a share of over 50%.	The raw material (Nd, Dy, Cu) stage of the supply chain exhibits the highest risks. These risks are also passed on to the manufacturing of permanent magnets which require these materials. The EU provides only 1% of the raw material for wind energy. Additional concerns pertain especially to the O&M stage and are based on potential cybersecurity concerns and availability of installation vessels for offshore wind

Solar PV supply chain

The solar PV market has moved from early and expensive niche market developments in the 1990s to a large-scale, globally deployed and increasingly competitive market. This development has been accompanied by technological progress, economies of scale and strong policy support. In 2019, the solar power sector increased by 13% to 116.9 GW.[53]

Thin-film technologies, which currently constitute ~ 5% of the solar PV technologies, contain the more critical raw materials. According to the JRC report the following raw materials used predominately in thin-film solar photovoltaics pose potential problems to the supply chain: **boron** (B), **gallium** (Ga), **indium** (In) and **silicon** (Si) (JRC, 2017). These are part of the 2020 EU list of critical raw materials. Under medium- and high- demand scenarios for Solar PV by 2050, significant material pressure is predicted for several materials, in particular, **tellurium**, **indium**, **selenium** and **silicon**.[54] The demand for structural material availability including: concrete, steel, plastic, glass, aluminium and copper could increase by a factor of between 2 and up to 21- times by 2050, depending on the scenario.[55]

Although manufacturing capacity has largely moved to Asia, European firms continue to maintain a strong presence in industry. European companies are most competitive in the downstream activities of the value chain related to monitoring and control, balance of system and solar trackers. EU firms are also important players in systems development and operation worldwide Potential critical dependencies mainly relate to the production of PV cells, modules and inverters. While there are some equipment manufacturers in Europe, and especially Germany, that still supply machinery and equipment to produce highly efficient solar cells and modules, the production of cells and modules has almost entirely migrated to Asia. The EU has a slightly stronger position in module manufacturing and hence a lower external dependence. The inverter industry was highly concentrated, with production in the top four countries comprising 78.0% of the global total in 2017. However, with one of the top four producers headquartered in Germany and one headquartered in Switzerland (a party to the Schengen Agreement) and with European countries (including Switzerland) accounting for 27% of the total global market in 2017, the observed concentration is currently not considered a threaten Europe’s energy supply or renewables deployment.

53 SolarPower Europe. (2020). EU Market Outlook for Solar Power 2019 – 2023.
54 JRC. (2020). Raw materials demand for wind and solar PV technologies in the transition towards a decarbonized energy system.
55 Ibid.

Table 1-12 Overall assessment for solar PV supply chain

Overall assessment for solar PV supply chain	
Strengths	**Weaknesses**
Solar PV, together with wind, is expected to lead the transformation towards renewable-based energy in Europe and globally. European companies are most competitive in the downstream activities of the value chain related to monitoring and control, balance of system and solar trackers. EU firms are also important players in systems development and operation worldwide. R&I activity is strong in Europe with centres such as CEA-Ines or Fraunhofer.	EU contribution is currently marginal in in the raw materials and manufacturing and assembly stages of the supply chain. China's role becomes quasi-monopolistic at the components stage, resulting in a high supply risk. The EU only provides 1% of silicon-based PV assemblies.

Hydropower + pumped hydro storage supply chain

Hydropower is based on a basic physical concept. Hydropower plants convert the potential or gravitational energy of water first into mechanical and then into electrical energy: the flow of water turns a turbine, which is connected to a generator. Hydropower includes stations operating with large water quantities stored in artificial reservoirs behind dams called storage power plants, run-of-river projects utilising the real-time natural flow of water bodies, and pumped hydropower storage (PHS). An additional type of systems is conduit hydropower that utilises the available energy in the conduit systems of e.g. water distribution, irrigation, and sewage networks. Different types of turbine have been developed, such as Pelton, Francis and Kaplan to mention the most commonly used, in order to have the highest efficiency in power generation for different ranges of head and flow.

Hydropower uses materials such as **steel**, concrete (**cement**), and **copper**. Concrete is used for dam construction and the required civil works including the power station building. Almost half of the installation cost (45% on average) of a hydro project relates to civil works. Hydropower dam development involves excavation and tunnelling, leading to the significant use of energy and explosives. Like for any civil works, some quantities of timber, **aluminium**, plastics are required.

The manufacture of mechanical components for hydropower typically uses steel, because of its mechanical strength and resistance to corrosion. Composite materials such as **fibre-reinforced composites** can be used to save weight and reduce manufacturing cost and environmental impact, especially for the small (below 10 MW) to micro-sized (below 100 kW) turbines. Copper is used at relatively lower quantities in the generator sets.

In the manufacturing stage, the two main categories of goods associated with hydropower technology in the PRODCOM[56] are: "hydraulic turbines and water wheels" and "parts for hydraulic turbines and water wheels". With a share of 32.4% on the Chinese market & 56.2% on the market outside China, EU manufacturers can be considered having a leading role and being global leaders., although EU27 investments in hydropower have been limited in the recent past. In terms of O&M, steel and copper is required for the replacement of **runners**, **rotors** and the **windings of the generator**, respectively.

[56] Eurostat. (2018). Prodcom List 2019. Available at: https://www.ine.es/en/daco/daco42/encindpr/lista_prodcom_en.pdf

Table 1-13 Overall assessment for hydropower + pumped hydro storage supply chain

Overall assessment for hydropower + pumped hydro storage supply chain	
Strengths	**Weaknesses**
EU HTG manufacturers can be considered as global leaders.	The construction stage is at risk, due to lengthy permitting procedures.

Nuclear fission supply chain

The nuclear fission supply chain is highly complex, with some of the main elements comprising the reactor vessel, the control and fuel rods system, the steam generator, the turbine and generator, the back-up diesel system, radiology and SCADA systems.

The manufacturing of the structures, systems and components of a NPP require a large number of raw and processed materials. The EU is highly reliant in imports for a number of raw and processed materials, with an import reliance ratio of around or over 60% for **zinc, nickel and chromium**. Moreover, for all these materials the foreign supply market is highly concentrated, with again the CR4 ratio being of around or over 60%. There are no or low dependency concerns for steel and concrete, as well as for nickel alloys, as the German VDM metals is a leading manufacturer of alloy 690 (together with the US-based Special Metals Corporation).

In 2018, the EU-27 had a **trade surplus in nuclear reactors, but a trade deficit for reactor parts**, importing around 51% of its apparent demand from China, the US, Japan and Russia. Major international **nuclear energy technology vendors** include Framatome (FR), Rosatom (RU) Westinghouse (US), GE Hitachi (US/JP), Mitsubishi Heavy Industries (JP), Toshiba (JP) and others. Some of these companies have filed for bankruptcy in recent years – such as Westinghouse, which is still active in the nuclear reactor market. In other cases, these technology vendors have pulled out of specific NPPs projects. This can lead to delays in the commissioning of nuclear power plants and even require the switch to other suppliers/technology vendors. The share of European countries in patenting related to nuclear energy among OECD countries has decreased continuously since the 60s, and Europe was overtaken as world leader in patenting in the 80s by South Korea, Japan and China. Total nuclear R&D spending in the OECD countries has decreased markedly since the Fukushima disaster in 2011.[57]

For very large modern nuclear reactors (Gen III+) **forging of the pressure vessel** becomes an important supply chain bottleneck, as it requires large forging presses which are scarce worldwide and which can handle only a few vessels per year (together with orders from other economic sectors). Specifically, heavy forging capacity in operation is concentrated in Japan, China, France, and Russia. Europe lists 8 heavy forging presses overall. Furthermore, new capacity is being built in Japan and China. The US has no comparable forging capacity.

With the reduced construction rate for nuclear energy plants in various regions and in Europe especially, challenges also arise related to capability, i.e. the sufficient availability of qualified personnel to design, build and operate the plants, including in the products and services supply chain. The sourcing of products and services is important not only for new reactor build, but also for the maintenance or upgrade of units.[58] European operators of nuclear facilities are facing challenges due to the obsolescence of 'structures, systems and components' (SSCs) and to the **difficulties in finding certified suppliers** for these SSCs when they need to satisfy higher quality standards. It is difficult in the EU to find suppliers willing to keep QA program when there is not certainty on future demand.[59] The availability of certified suppliers is worsened by the use of different standards and quality management systems in various countries and regions, which limits the possibility for international sourcing of component and leads to additional certification costs. Furthermore, technical barriers to exports limit the capacity for sourcing components internationally.[60]

[57] Breakthrough Institute. (2017). How to make nuclear innovative.
[58] World Nuclear Association. (2020). Launch of the World Nuclear Supply Chain: Outlook 2040 report.
[59] JRC in World Nuclear Association. (2020). Launch of the World Nuclear Supply Chain: Outlook 2040 report.
[60] International Framework for Nuclear Energy Cooperation. (2017). Global Supply Chain and Localization, Issues and Opportunities: A Conference on the Customer Dialogue – Summary Conference Report.

Table 1-14 Overall assessment for nuclear fission supply chain

Overall assessment for nuclear fission supply chain	
Strengths	**Weaknesses**
There are no or low dependency concerns for steel and concrete, as well as for nickel alloys, as the German VDM metals is a leading manufacturer of alloy 690. In 2018, the EU-27 had a trade surplus in nuclear reactors,	The EU is highly reliant in imports for a number of raw and processed materials, with an import reliance ratio of around or over 60% for zinc, nickel and chromium. For very large modern nuclear reactors (Gen III+) forging of the pressure vessel becomes an important supply chain bottleneck, as it requires large forging presses which are scarce worldwide. Challenges due to the obsolescence of 'structures, systems and components' (SSCs) and to the difficulties in finding certified suppliers

Hydrogen production, storage and use supply chain

The Hydrogen (H_2) Production, Storage and Use supply chain comprises:

- Hydrogen fuel cells (FCs) (for stationary & mobile applications);
- Hydrogen for other end-use applications (industrial processes e.g. H_2 replacing coking coal in iron industry; gas turbines; conventional boilers; …);
- Renewable hydrogen production (the recently launched "Hydrogen Strategy for a climate neutral Europe"[61] aims at fostering a significant growth in European electrolyser capacity);
- Hydrogen storage (stationary and mobile applications)

FCs and electrolysers use catalysts, commonly made from platinum-group metals (PGMs), given their unique chemical and physical properties. Due to high platinum material costs, the technology cost is sensitive to the amount of catalyst required.[62] Polymer electrolyte membrane (PEM) electrolysers resemble PEM fuel cells to some extent, though corrosion-resistant materials such as titanium are used. For hydrogen production technologies[63], no particular material or component stands out in cost or supply risk. The main cost contributors are the cell components – anode and cathode, as well as the bipolar plates and the membrane or diaphragm, depending on the specific design.

Around 30 raw materials[64,65] are needed for producing FCs, electrolysers and hydrogen mobile storage technologies. Of these materials, 14 materials are deemed critical for the EU economy (namely cobalt, magnesium, rare-earth elements (REEs), platinum, palladium, borates, silicon metal, rhodium, ruthenium, graphite, lithium, titanium, iridium and vanadium). Platinum is produced mainly in South Africa (71% of global production), followed by Russia (16%) and Zimbabwe (6%). The other PGMs, namely palladium, rhodium and iridium are also supplied predominantly by three key suppliers: Russia, South Africa and Zimbabwe. The global supply of all raw materials required is diversified with more than half of the materials coming from a variety of suppliers, each with a small supply share of less than 7%. China, with more than 20% share, is the major supplier of raw materials, followed by South Africa and Russia. Regarding Critical Raw Materials (CRMs) used in fuel cells, China has the dominant position with 34%, followed by South Africa and Russia. **Among these raw materials, only PGMs, REEs and titanium are considered highly vulnerable.**

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[61] European Commission. (2020). A Hydrogen Strategy for a climate neutral Europe. Available at: https://ec.europa.eu/commission/presscorner/api/files/attachment/865942/EU_Hydrogen_Strategy.pdf.pdf
[62] James et al. (2017). Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2016 Update. Available ata; https://energy.gov/sites/prod/files/2017/06/f34/fcto_sa_2016_pemfc_transportation_cost_analysis.pdf
[63] E4tech (UK) Ltd for FCH 2 JU in partnership with Ecorys and Strategic Analysis Inc. (2019). Study on value chain and manufacturing competitiveness analysis for hydrogen and fuel cells technologies (FCH contract 192): Evidence report. Available at: https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf
[64] Ibid.
[65] Blagoeva, D., Pavel, C., Wittmer, D., Huisman, J. and Pasimeni, F. (2019). Materials dependency for dual-use technologies relevant to Europe's Defence sector, EUR 29850 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-11101-6, doi:10.2760/279819, JRC117729.

12 processed materials[66] are identified as the most relevant processed materials. Europe appears to be the major supplier of processed materials for fuel cells (40 %), followed by the USA (28%), China (10%) and Japan (7%).[67] However, hydrogen compressed tank supply has some strong Asian and North American players[68], with limited production in Europe, and with Japan as main **carbon fibre** supplier, which has been considered as a weakness in the supply chain. However, given the fact the fuel cells market is now developing, carbon fibre manufacturers are investing to increase their EU capacity, which is also used in other critical energy chains.
The possible restriction and ultimately ban of all PFAs ("per and polyfluorinated alkyl substances"), in the frame of the EU PFAS Strategy[69], could lead to a serious threat on supply of polymer electrolyte membranes, as there are currently no alternatives.

Europe also enjoys relatively strong position in terms of supplying components[70], providing around 25% of global supply, behind North America (44%), followed by Asia (31 %). Finally, the stack design and cell assembly are very important steps that can influence the performance of fuel cells and distribution of reactants in the cell stack. The market share of the Fuel Cell System Manufacturing was dominated by Asia and North America, still in 2017, but this is now evolving as most of the industrial actors in Europe are increasing their activity. Europe is one of the leaders in today's global **alkaline electrolysis** industry.[71] The components for **alkaline electrolysers** can generally be sourced within Europe.[72]

Finally, the stack design and cell assembly are very important steps that can influence the performance of fuel cells and distribution of reactants in the cell stack. The assembly of fuel cell stacks and systems also appeared to be critical. While, still recently, most FCs assemblers and system integrators were still headquartered outside EU, the recent development of EU industry led to raising production capacities and assembling activities in Europe.

Table 1-15 Overall assessment for hydrogen production, storage and use supply chain

Overall assessment for hydrogen production, storage and use supply chain	
Strengths	**Weaknesses**
Europe is a major supplier of processed materials for fuel cells (40 %). It also enjoys a strong position in terms of supplying components, providing around 25% of global supply. Europe is one of the leaders in today's global alkaline electrolysis industry.	The hydrogen & fuel cell industry relies heavily on platinum group metal (PGM)-based catalysts. About half of the final costs depend on this material which is sourced from outside of the EU. PEM electrolysers manufacturing relies on increased use of Titanium (power electronics, with Titanium-based bipolar plates and meshes represents the second contributor to the cost, after the stack). The supply chain for compressed tanks is made of high-grade carbon fibres, which are largely imported from Asia. The stack design and cell assembly market share 2014-2017 of the Fuel Cell System Manufacturing

[66] Namely Porous carbon material; Polymer electrolyte – Perfluorinated Sulfonic Acid (PFSA); yttria stabilised zirconia ceramic; Carbon Fibre Composites (CFC); Graphene; Carbon Cloth / paper; Stainless steel; Carbon Nanotubes (CNTs); Scrap & flake mika; Metal hydrides; Polyamid ultramid; Boron nitride powder
[67] Blagoeva, D., Pavel, C., Wittmer, D., Huisman, J. and Pasimeni, F. (2019). Materials dependency for dual-use technologies relevant to Europe's Defence sector, EUR 29850 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-11101-6, doi:10.2760/279819, JRC117729.
[68] E4tech (UK) Ltd for FCH 2 JU in partnership with Ecorys and Strategic Analysis Inc. (2019). Study on value chain and manufacturing competitiveness analysis for hydrogen and fuel cells technologies (FCH contract 192): Evidence report. Available at: https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf
[69] European Commission. (2020). SWD(2020) 249 final. Poly- and perfluoroalkyl substances (PFAS). Available at: https://ec.europa.eu/environment/pdf/chemicals/2020/10/SWD_PFAS.pdf
[70] Such as Bipolar Plates, catalysts, Gas Diffusion Layers, membranes and hydrogen vessels.
[71] E4tech (UK) Ltd for FCH 2 JU in partnership with Ecorys and Strategic Analysis Inc. (2019). Study on value chain and manufacturing competitiveness analysis for hydrogen and fuel cells technologies (FCH contract 192): Evidence report. Available at: https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf
[72] Ibid.

	shows Europe's share reaching ~1% of the global production (Asia and USA being the leading regions). However, this market share has evolved rapidly these last years, as more and more hydrogen players are developing their assembly activity across Europe. There is still no market analysis publicly available, but the concerned stakeholders are considering this is no longer a weakness for EU supply chains[73].

Gasifiers (biomass) and gas turbines supply chain

Gas can be used to generate electricity in a variety of ways. Natural gas is most often used as the gas of choice, however gases derived from biomass can also be used in gas turbines to generate electricity. Gasification process converts biomass, a low-energy density material, into a gaseous product, which is a mixture of carbon monoxide, hydrogen, methane and carbon dioxide. The gaseous products from the gasifier can be utilized in gas engines or gas turbines for the generation of electricity (see section below). Gasifiers can be categorized into three main types: fixed bed gasifiers, fluidized gasifiers and the entrained flow gasifiers.

Combined Cycle Gas Turbines (CCGT) are the dominant gas-based technology for intermediate and base-load power generation. These plants have the same basic components as the Open Cycle Gas Turbines (OCGT) plants, but the heat associated with the gas-turbine exhaust is used in a heat recovery steam generator (HRSG) to produce steam that drives a steam turbine and generates additional electric power.

Gasifiers are made of metal alloys. They often contain corrosion-resistant materials such as **copper, brass, epoxy lined steel and stainless steel**. The components of the gas turbine are made up of a number of raw and process materials. The composition of these will differ depending on the type and design of the turbine. Initially, the primary focus in choosing the materials was based on high temperature tensile strength requirements. Often, **production blades for compressors are made from 12% chromium containing martensitic stainless steel** (grades 403 or 403 Cb). Combustion hardware has traditionally been made from nickel-base superalloys but has recently shifted to **cobalt-base superalloys**. Turbine discs of most gas engine single shaft heavy duty gas turbines are made of different **chromium, iron or nickel alloys**. Bucket (rotating airfoils) and nozzle materials for land base gas turbines are also made of different combinations of metal alloys. There are different types of coatings, often divided into aluminium (diffusion), overlay and thermal barrier coatings. These are based either on a combination of metal alloys of from ceramics for the latter type. We found no evidence in the literature to indicate concerns with the supply of raw materials, even those classified as critical according to the JRC[74], or alloys in the case of both gasifiers and gas turbines. This could be due to the small quantities needed for those materials that are considered critical.

Major **players in gasification are Royal Dutch Shell (NL), General Electric (GE)(US), Air Liquide (FR) and SEDIN Engineering Company Limited (CN),** who enjoy dominant positions in the market. Asia-Pacific market is the most dominant with the largest market share at present.

In addition to the turbine, a generator and the balance of plant components are required to run a gas power plant. Four out of the top ten turbine manufacturers are headquartered in EU27 countries and one of them in the UK. **Market concentration is not a major concern** for the security of supply of gas turbines in the EU27. However, **heavy duty turbine blades and vanes castings** could represent a potential fragility for the European gas turbine supply chain. Given that they are mostly sourced from non-EU countries.

The construction and installation of gas-based turbines requires a technically qualified workforce. Often, the manufacturers of gas-turbines also offer installation and O&M-related services. Companies such as GE, offer **customizable O&M service options** that involve either advisory

[73] The literature still considers the stack design and cell assembly activity as a weakness in Europe, but the interviewed industry representatives have been clear that the activity is deploying rapidly in Europe, mentioning a few important players in the hydrogen economy such as, for PEM, Autostack Industry (DE), the German consortium of the EU project Autostack-core (DE), ElringKlinger (DE, JV with Plastic Omium), PowerCell (SE), Symbio (FR, JV with Michelin & Faurecia), and for SOE, Elcogen (EE) ; Genvia (FR).
[74] Based on the JRC's Critical Raw Material List 2020.

services and training or contracting full-service operators to perform all day-to-day operational activities. Contracting options include multi-year agreements, which are based on strategies around performance and can evolve through the plant life cycle. Other services available are outage services, upgrades, field services and plant rehabilitation and relocation services. Furthermore, digitalisation solutions are becoming more and more popular given the opportunities they offer for the transformation of the electricity industry. According to GE, **digitalisation solutions can provide early warnings and signal the need for predictive maintenance, enable rapid turn-up and better management of fuel variability and emissions levels using advanced analytics and provide real-time visibility into power production** for plant managers and traders among other benefits. However, increased digitalisation of the power sector also poses an **increased risk of cyber attacks**.

Table 1-16 Overall assessment for gasifiers (biomass) and gas turbines supply chain

Overall assessment for gasifiers (biomass) and gas turbines supply chain	
Strengths	**Weaknesses**
Dutch and French companies are among the major players in gasifier technology. Well-developed manufacturing base in Europe. Market concentration is not a major concern.	Heavy duty turbine blades and vanes castings supplied mostly from outside of Europe. O&M services subject to cybersecurity risk.

Gas infrastructure supply chain

The main components in gas infrastructure are the pipes, compressors, valves, fittings, filters/scrubbers and cooling system. Centrifugal compressors are employed more frequently than reciprocating ones. Ball valves are also more common than butterfly ones.

The main processed material relevant for gas network supply chains is **steel**. The EU was a net exporter of iron and steel in 2019 (led by Germany, Italy, Belgium and the Netherlands). Main non-EU suppliers comprise Russia, Turkey, China and the UK, totalling a CR4 (concentration ratio of the 4 largest producers) of around 44% for imports from outside the EU.[75]

The EU is a net exporter of seamless **steel pipes**, generally used for high-pressure application such as gas transmission, with imports representing <20% of intra-EU consumption. Imports are more significant for longitudinally-welded pipes (over 50% of intra-EU consumption), although the EU is still a net exporter. Exporters of longitudinally-welded pipes to the EU comprise Russia, Brazil, South Korea and Japan. Imports of polyethylene pipes represent only a small share (<10%) of the EU consumption. A gas TSO also indicated that low quotas for imports from third countries for some pipeline elements (especially large diameter pipes) can lead suppliers to spread deliveries in order to maintain imports within quota limits (and thus have lower custom tariffs), leading to long delivery times. In 2019 the EU imposed definitive safeguard measures (import quotas) to certain steel products.[76] Orgalim, an association representing European technology industries, argued in June 2020 that a proposed review of the safeguards would restrict the flexibility of downstream steel European users, while the "impact of COVID-19 on production and demand in the EU steel market cannot yet be quantified".[77]

Major European **centrifugal compressors** manufacturers comprise Siemens (DE), MAN (DE), Nuovo Pignone (based in IT - owned by GE, US) Atlas Copco (SE), Ingersoll Rand (IE) and Burckhardt Compression (CH). Non-EU manufacturers comprise GE (US), Baker Hughes (US), Ariel Corporation (US).[78] Compressors are not identified as a vulnerable element.

[75] Eurostat. (2020). International trade in goods by type of good.
[76] Commission Implementing regulation (EU) 2019/159 imposing definitive safeguard measures against imports of certain steel products. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.031.01.0027.01.ENG
[77] Orgalim. (2020). Letter on the Review of the safeguard measures against imports of certain steel products. Available at: https://orgalim.eu/sites/default/files/attachment/Orgalim%20letter%20steel%20safeguard_220620.pdf
[78] Mordor Intelligence. (2020). Centrifugal compressor market – growth, trends, COVID-19 impact, and forecasts. Available at: https://www.mordorintelligence.com/industry-reports/global-centrifugal-compressors-market-industry

EU imports of **ball valves**[79] respond for over 60% of apparent consumption, although CN codes cover a wide range of valve types and sizes. Extra-EU supply is highly concentrated (CR4 >80%), with major suppliers being China, Switzerland, Taiwan and the UK. A central European gas TSO indicated that often semi-finished products have indeed to be imported from China to the EU, for example cast iron bodies for valve manufacturing.[80] Major valve manufacturers for oil & gas comprise Cameron (US), Emerson (US), Flowserve (US) and AVK (DK) – with thus an important concentration of US manufacturers, although Italian manufacturers may also be important to the oil & gas sector generally. [81]

A more vulnerable element for gas infrastructure appears to be **filters and purifiers**. PRODCOM data indicates a high import reliance in the category (>90%), although the category is broad ("Machinery and apparatus for filtering and purifying gases (other than air)"). Global market leaders of industrial filtration elements include Danaher (US) and Donaldson (US).[82]

Tens of **LNG re-gasification terminals** have been constructed in the last few years or are scheduled for commissioning until 2023. The majority is located in Asia, but Poland and France commissioned new terminals since 2015, Croatia's terminal was commissioned in January 2021, and Finland and Cyprus should commission others in 2021.[83] Most LNG vessels are currently built by South Korean or Chinese shipyards.[84]

Dependence on spare parts to address planned and unplanned maintenance requirements is a potential vulnerability given the supply chain for the main components such as pipelines, compressor parts and other elements (valves, gaskets) is integrated. However, gas TSOs deem the global market sufficient diverse, and **have not indicated the supply of parts to be a particular concern**. Moreover, alternative suppliers for e.g. compressor parts exist, providing more options than just the original equipment manufacturers. Terrorism is also identified as a relevant risk for pipelines[85], although studies in this aspect and the connections to the gas pipeline supply chains not available.

Underground gas storage sites were being constructed in 2018 in the Czech Republic, Germany, Italy, Poland and Portugal. Generally, these facilities have been designed by EU companies (such as Bilfinger Tebodin, Saipem, Control Process), usually of the same Member State as of the site itself.

Concerning **hydrogen infrastructure technology**, the US is the leader in hydrogen transport pipelines, with over 2 600 km around 2016. Europe has the second longest hydrogen network, with around 1 600 km in 2016. The main companies operating hydrogen networks in Europe are Air Liquide (FR), Air Products (US) and Linde (DE-US). Both Air Liquide and Linde have engineering divisions providing services to the group but also to third parties, including for the design of LNG terminals in the case of Linde. Furthermore, Air Liquide operates the third longest hydrogen network in the US (545 km in 2016), after Praxair (US) and Air Products.[86] The only hydrogen storage site in Europe is located at Teeside (UK).[87]

Recently increased attention has been paid to cybersecurity of gas networks.[88] As for the electricity system, gas network control systems could be compromised through ITC service providers, unintentional vulnerabilities or backdoors added in equipment during the design, manufacturing or

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[79] Includes also plug valves.
[80] Information based on direct communication with the TSO
[81] Euractiv. (May 19, 2020). Coronavirus creates repair headache for oil and gas industry. Available at https://www.euractiv.com/section/energy/news/coronavirus-creates-repair-headache-for-oil-and-gas-industry/
[82] Markets and Markets. (2020). Industrial Filtration Market.
[83] International Gas Union. (2020). World LNG Report 2020. Available at: https://www.igu.org/wp-content/uploads/2020/04/2020-World-LNG-Report.pdf
[84] Ibid.
[85] Pedersen et al. for the EP Policy Department A. (2009). An Assessment of the Gas and Oil Pipelines in Europe. Available at: https://www.msp-platform.eu/sites/default/files/gas_and_oil_pipelines_in_europe_en.pdf
[86] Hydrogen Analysis Resource Center. (2016). Hydrogen Pipelines Database. Available at: https://h2tools.org/hyarc/hydrogen-data/hydrogen-pipelines
[87] Tarkowski, R. (2019). Underground hydrogen storage: Characteristics and prospects. Renewable and Sustainable Energy Reviews, 105, 86-94
[88] For example, ENTSOG/ GIE joint Cybersecurity TF. (2019). Available at: https://www.ceer.eu/documents/104400/-/-/2c424b85-e79a-13b4-6265-a7eb0c6dc8c1;
Council of European Energy Regulators. (2018). Cyber Security Work Stream: CEER Cybersecurity Report on Europe's Electricity and Gas Sectors. Available at: https://www.ceer.eu/documents/104400/-/-/684d4504-b53e-aa46-c7ca-949a3d296124

shipping stages. Actions to address this risk are being taken in the US.[89] German gas TSOs indicate that, in the scope of the ISO/IEC 27001 standard on information security, there are supplier control mechanisms for cybersecurity.

Table 1-17 Overall assessment for gas infrastructure supply chain

Overall assessment for gas infrastructure supply chain	
Strengths	**Weaknesses**
Many major European for pipes, centrifugal compressors manufacturers, hydrogen infrastructure technology. Diverse international market for most equipment and parts.	EU imports of ball valves respond for over 60% of apparent consumption. Extra-EU supply is highly concentrated (CR4 >80%). A more vulnerable element for gas infrastructure appears to be filters and purifiers. High import reliance in the category (>90%).

Electricity networks supply chain

As shown in section 1.1, due to electrification electricity networks could go from presently transporting around a quarter of the energy consumed in the EU to transporting over half of that energy in 2050. Therefore, electricity networks are and will continue to be a key component of the EU energy system, enabling a range of other critical energy technology supply chains.

The main components of electricity lines are cables and conductors. Electricity transmission lines can be overhead, in which case conductors are not insulated, or underground, where cables are insulated. Cables and conductors are made of copper or more frequently aluminium, while the most common insulation methods are extruded cross-linked polyethylene (XLPE) or mass-impregnated cables. In addition, to cables and conductors, transformers and AC/DC converters, the other main components comprise switchgears, tower, pylons and insulators, and SCADA (supervisory control and data acquisition) systems[90] as well as a number of processed and raw materials.

Due to the number of equipment and components for electricity networks, there is not a single overview of the entire supply chain. The main elements per supply chain stages are indicated in Figure 1-7, to illustrate the characterisation conducted for each selected supply chain in this study. Further details are available in the supply chain fiche of Annex B.

Neither aluminium nor copper are included in the latest, 4th EU list of critical raw materials published in September of 2020. **Silicon metal**, however, is a critical raw material[91] employed in the electronics embedded in the converters and elsewhere in the electricity networks (digital technologies are analysed as a separate supply chain).

The main processed materials are employed in the manufacturing of the cables, insulators and towers, and transformers. There is an import dependency for low-density **polyethylene** (used for developing XLPE cables) of around 35%. Transformer mineral oil insulation and coolant could become critical materials in the future but are not assessed so at the moment by the industry.

The analysis of the market shares of global **power cable** manufacturers[92] indicates that Prysmian, General Cable and Nexans (a French company) had over 50% of the EEA market share for different cable classes in 2016 (HV/EHV underground, LV/MV and HV/EHV submarine cables). NKT cables (a Danish company) is generally the following largest manufacturer after Prysmian, General Cable and Nexans. In 2019 the industry association Europacable assessed that the manufacturing capacity of European cable manufacturers would be sufficient to match the forecasted demand for submarine

[89] Public-Private Analytic Exchange Program. (2017). Supply Chain Risks of SCADA/Industrial Control Systems in the Electricity Sector: Recognizing Risks and Recommended Mitigation Actions. Available at: https://www.odni.gov/files/PE/Documents/11---Supply-Chain-Risks-of-SCADA-Industrial-Control-Systems-in-the-Electricity-Sector_Risks-and-Mitigations.pdf
[90] Cretì, A., & Fontini, F. (2019). Electricity Systems and the Electricity Supply Chain. In Economics of Electricity: Markets, Competition and Rules, 35-49. Cambridge: Cambridge University Press. doi:10.1017/9781316884614.004
[91] JRC. (2020). Study on the EU's list of Critical Raw Materials. Available at: https://ec.europa.eu/jrc/en/news/jrc-assesses-critical-raw-materials-europe-s-green-and-digital-future
[92] European Commission DG Competition. (2018). Case M.8770 - Prysmian/General Cable. Available at: https://ec.europa.eu/competition/mergers/cases/decisions/m8770_722_3.pdf

cables considering the ENTSO-E's TYDNP 2018.[93] The import dependency of the EU is relevant for **glass and porcelain insulators**, with an import ratio of around 40% according to PRODCOM data. The EU is a net exporter of ceramic and glass insulators and related components.[94][95]

Transformer manufacturing employs domain-refined high-permeability **grain-oriented electrical steel** (GOES). The capacity of EU suppliers for this GOES type can satisfy only a share of the forecasted EU demand, especially for the highest permeability grades.[96] For **large transformers**, the EU production is larger than imports.[97] PRODCOM data indicates that the EU import ratio was under 25% for transformers with a capacity larger than around 500 kVA, and much lower for even larger transformers (above 10 MVA). The main European manufacturers (Siemens, ABB Group, CG Power System, and Schneider Electric)[98] are important global players.

There are no specific bottlenecks identified for **voltage-source converters**, with ABB and Siemens being major manufacturers.[99] PRODCOM data does that there is a certain dependency on static converters imports, which equal the EU-27 production in value, but this comprises a larger range of converter types and sizes. China is a leader in the development and deployment of multiterminal HVDC systems,[100] which would be necessary for the development of an offshore grid.

Other elements such as **cabinets & boards, power electronics and switchgear** do not constitute a particular vulnerability. Companies such as Hitachi ABB (JP/SE/CH) and Siemens (DE) retain strong market shares, along non-EU companies such as China XD (CN), NR Electric (CN) and General Electric (US). Compared to the US and especially Asian countries, the EU does have a very low share of global patents for several elements, including power electronics.[101] Stakeholders have also not indicated any particular vulnerability related to the manufacture or installation of **electricity transmission towers and** pylons.

Cybersecurity of the electricity system is an important concern. Cyber vulnerability of electricity networks is directly related to cyber vulnerability of digital technologies employed in the energy sector in general, and is thus further assessed in that supply chain vulnerability assessment.

[93] EUROPACABLE. (2019). Demand and Capacity for HVAC and HVDC underground and submarine cables. Available at: https://europacable.eu/wp-content/uploads/2021/01/Europacable-Communication-Demand-and-Capacity-for-HVAC-and-HVDC-cables-24-Sept-2019.pdf

[94] CEPS, Economisti Associati and Ecorys for DG GROW. (2017). Cumulative Cost Assessment (CCA) of the EU Ceramics Industry. Available at: https://www.ceps.eu/download/publication/?id=10192&pdf=CCA%20CERAMICS_FinalReport.pdf

[95] CEPS, Economisti Associati and Ecorys for DG GROW. (2017). Cumulative Cost Assessment (CCA) of the EU Glass Industry. Available at: https://www.ceps.eu/download/publication/?id=10198&pdf=CCA%20GLASS_Final%20Report.pdf

[96] Commission Implementing Regulation (EU) 2015/1953 imposing a definitive anti-dumping duty on imports of certain grain-oriented flat-rolled products of silicon-electrical steel originating in the People's Republic of China, Japan, the Republic of Korea, the Russian Federation and the United States of America.

[97] Almeida, A.D., Martins, F., Santos, B. (2013). Impact Assessment Implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign Requirements for Power, Distribution and Small Transformers.

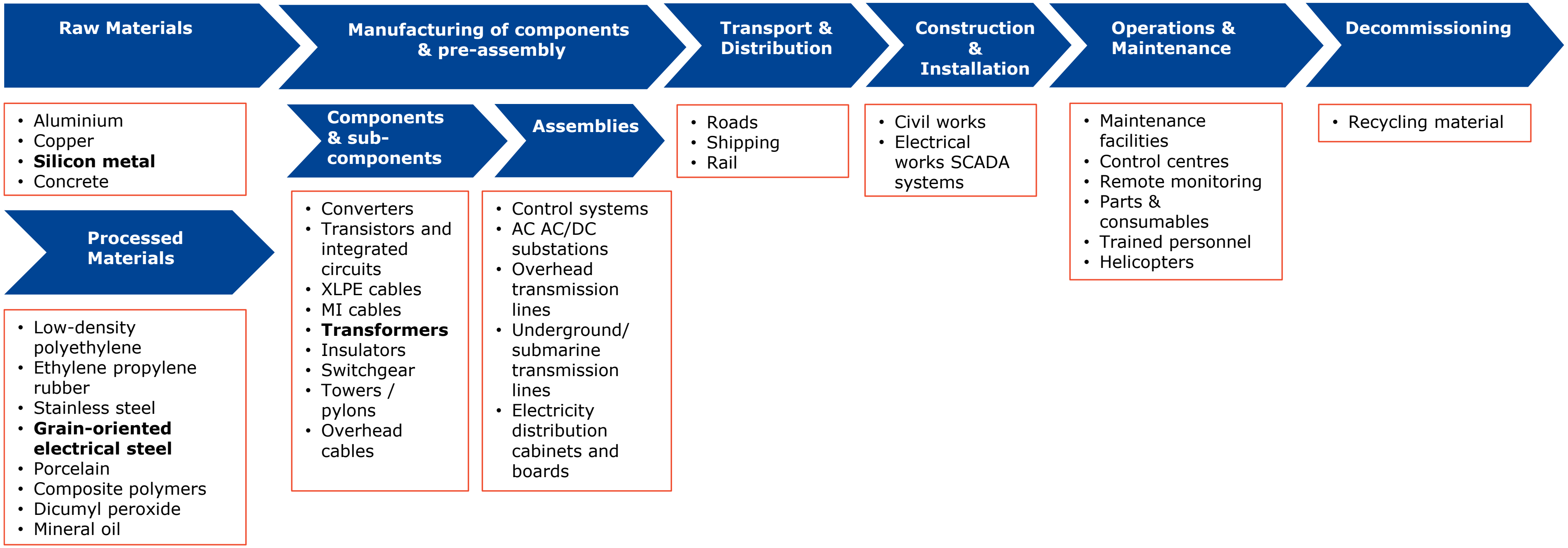
[98] Coté et al. (2018) Market Analysis of the Offshore Wind Energy Transmission Industry. Available at: http://www.baltic-integrid.eu/index.php/download.html?file=files/baltic_integrid/Arbeitspaket%202/WP%203%20Development%20of%20the%20Baltic%20Grid%20Concept/3.2%20Market%20%26%20Supply/Outputs/BIG_3.2_Market%20Analysis%20of%20the%20Offshore%20Wind%20Energy%20Transmission%20Industry_final.pdf

[99] Ibid.

[100] DG ENER. (2020). Workshop: Horizon 2050 power system and the role of HVDC technologies in a highly decentralised RES generation.

[101] European Commission. (2020). Report on progress of clean energy competitiveness. COM(2020) 953.

Figure 1-7 The supply chain of electricity network technologies[102]



*Note: vulnerable elements found highlighted in **bold**.*

[102] Own elaboration and based on Kumara et al. (2020). Electrical Characterization of a New Crosslinked Copolymer Blend for DC Cable Insulation.

Table 1-18 Overall assessment for electricity networks supply chain

Overall assessment for electricity networks supply chain	
Strengths	**Weaknesses**
The EU is a net exporter of ceramic and glass insulators and related components. For large transformers, the EU production is larger than imports. There are no specific bottlenecks identified for voltage-source converters, with ABB and Siemens being major manufacturers.	Silicon metal is a critical raw material employed in the electronics embedded in the converters and elsewhere in the electricity network, with the EU having an import dependency in the order of 60%. There is some import dependency for low-density polyethylene (35%). Cybersecurity of the electricity system is an important concern.

Batteries supply chain

Batteries are energy storage technologies based on the principle of electrochemistry. They can convert chemical energy into electrical energy. Batteries are based on a wide range of different chemistry processes. They can be divided into primary (single use) and secondary (rechargeable) batteries. Given the predominance of Lithium (Li)-ion batteries (LIB), the focus will be on this type of technology.

Cobalt (Co)is an important raw material used in the production of the cathode of LIB. It is also used in the production of other batteries. In 2017, 60.85% of cobalt worldwide came from the Democratic Republic of Congo. China was the second largest producer with 6.64% of the share followed by Canada (4.8%) and Cuba (4%). Analysis points to potential deficit in cobalt supply despite efforts to substitute the material.[103] Cobalt is expected to see a spike in demand, growing 500% by 2030 and 15 times by 2050.[104] In 2017, **lithium** (Li) was mostly produced in Australia (49.3%), Chile (30.3%), Argentina (11.52%) and China (4.57%). The supply of lithium is not expected to be a major issue for the battery supply chain in the short or medium term given that there is sufficient capacity available in the near future. Nevertheless, an increase from current prices could be necessary to support the development of new production capacity.[105] Demand for Li is expected to increase 16-fold by the end of the decade and be 60 times larger by 2050. However, this reliance is forecasted to diminished significantly based on European mining projects being developed. **Natural graphite** is another important raw material in the batteries supply chain. China supplies about 71% of the global production followed by Brazil, North Korea and India. Manufacturing of anode materials in batteries makes up for around 10% of the global natural graphite demand. Natural graphite can be substitutes by a synthetic version. About two-thirds of **nickel** (Ni) ore is produces in the following counties: Indonesia, the Philippines, Australia, Russia and Canada. China produces around 30% of the refined nickel. It is important to note that not all nickel is suitable to produce LIB. Although the supply of nickel is more diversified compared to cobalt and lithium, Europe still relies for imports of this material with a share of ~ 56%.

Asia, and more specifically China, dominates the entire LIB supply chain. China provides 48% of the total processed materials and components and together with Japan and South Korea make up 86% of all processed materials and components for LIB. Li-ion cell production in Europe is well below the 1% of the global share. Europe currently lacks the capacity to process materials required to produce LIB, such as anode materials and NCA cathode materials. Europe is fully dependent on the supply of lithium, processed natural graphite, artificial graphite, NCA cathode material, anodes and separators. For producing Electric Vehicle (EV) battery packs, the European capacity is currently of 3GWh, this capacity is expected to grow to about 40 GWh by 2021-2023.[106]

Europe is catching up with Asia in terms of investments in the battery sector. In fact, Europe invested significantly more than China in the sector in 2019 (60 billion EUR vs 17 billion EUR). This year,

[103] Alves Dias P., Blagoeva D., Pavel C., Arvanitidis N. (2018). Cobalt: demand-supply balances in the transition to electric mobility, EUR 29381 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-94311-9, doi:10.2760/97710, JRC112285.. Available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC112285/jrc112285_cobalt.pdf
[104] European Commission. (2020). Raw Material Information System (RIMS) – Raw Materials in the Battery Value Chain. Available at: https://rmis.jrc.ec.europa.eu/apps/bvc/#/
[105] Roskill. (2019). Lithium: current prices provide limited incentive for new supply. Available at: https://roskill.com/news/lithium-current-prices-provide-limited-incentive-for-new-supply/
[106] Triropoulos, I. et al. (2018). Li-ion batteries for mobility and stationary storage applications. Available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC113360/kjna29440enn.pdf

Europe has invested 25 billion EUR, corresponding to double the investments by China.[107] In July of 2020, the European Investment Bank issues a 30 million EUR loan for the construction of the first domestic battery giga-factory. The factory will be constructed in Sweden by Northvolt, with plans for an initial annual production capacity of 16 GWh. This capacity could eventually be ramped up to 40 GWh.[108][109] Other factories are planned in DE and FR.

Table 1-19 Overall assessment for batteries supply chain

Overall assessment for batteries supply chain	
Strengths	**Weaknesses**
Europe is catching up with Asia in terms of investments in the battery sector. In fact, Europe invested significantly more than China in the sector in 2019 (60 billion EUR vs 17 billion EUR).	Bottlenecks for the EU are in the raw materials (Co, Si, P, F, Li, C, Nb, Ti) stage and the Li-ion cells manufacturing. Currently, the EU provides less than 1% of Li-batteries

Smart building and building automation supply chain

Building energy management systems (BEMS) and home energy management systems (HEMS) comprise the IT software and hardware to extend the capabilities of and is intrinsically linked to the digitalisation of building and home equipment and appliances. Home and building energy management systems are also highly linked to the development of other digital energy technologies, such as distributed energy resources management systems, and to other building equipment and appliances related to lighting, heating, ventilation and air conditioning (HVAC), decentralised renewable energy supply, and energy storage.[110]

Twelve (groups of) raw or processed materials are critical for smart buildings automation technology, mostly related to the manufacturing of digital technology components (analysed separately), but also including the rare-earth elements employed in LED manufacturing. LED manufacturing requires **arsenic as well as the rare-earth elements (REEs) cerium, europium, gadolinium, lanthanum, terbium, and yttrium**.[111]

Major **building automation and control systems (BACS)** suppliers for the EU market comprise Siemens Building Technologies (DE), Honeywell Technologies (US), Johnson Controls (US), Schneider Electric Buildings (FR), and Kieback & Peter (DE). The first four companies would account for 54% of the non-residential European market. A list of over 25 companies members of the eu.bac industry association accounts for 85% of the European BACS market. Many of those are based in Germany or Switzerland (although this includes European branches of Honeywell and Johnson Controls).[112]

The market for **energy management and related software** is in general highly concentrated, with European players having a strong position for many software categories. For BEMS specifically, the EU is a leader. Lead suppliers of BEMS include Schneider Electric (FR), Siemens (DE), Honeywell (US), Johnson Controls (US) and Switch Automation (US). Others comprise EcoEnergy Insights (US), Acuity Brands (US) and ThoughtWire (CA).[113] ABB (CH), GE and Eaton (US) also provide BEMS systems.[114] The US is a leader in **home energy management software** (HEMS), with only Schneider Electric (FR) being a main supplier based in Europe.[115] Lead US-based HEMS vendors include Bidgely, Itron, Oracle and Uplight.

[107] Euractiv. (November 9, 2020). Raw materials: the missing link in Europe's drive for batteries. Available at: https://www.euractiv.com/section/energy-environment/news/raw-materials-the-missing-link-in-europes-drive-for-batteries/
[108] Euractiv. (August 28, 2020). Europe is 'closing the gap' on battery manufacturing, Northvolt says. Available at: https://www.euractiv.com/section/energy-environment/news/europe-is-closing-the-gap-on-battery-manufacturing-northvolt-says/
[109] Euractiv. (July 30, 2020). EU invests EUR350m in first domestic battery Gigafactory. Available at: https://www.euractiv.com/section/batteries/news/eu-invests-e350m-in-first-domestic-battery-gigafactory/
[110] Yoon et al. (2018). Multiple power-based building energy management system for efficient management of building energy. Sustainable Cities and Society, 42, 462-470.
[111] European Commission. (2020). Clean Energy Transition – Technologies and Innovations. SWD(2020) 953.
[112] VITO, WSE and Ricardo. (2020). Ecodesign preparatory study for Building Automation and Control Systems (BACS) implementing the Ecodesign Working Plan 2016 - 2019 Draft final - Task 2 report: Markets.
[113] Guidehouse. (2020). Insights Leaderboard: Intelligent Building Software.
[114] E-LAND. (2019). D7.1 Market and stakeholder analysis. Available at: https://elandh2020.eu/wp-content/uploads/2020/09/D7.1-Market-and-stakeholder-analysis.pdf
[115] European Commission. (2020). Clean Energy Transition – Technologies and Innovations. SWD(2020) 953.

Lighting products are important given that leading companies in the field are increasingly involved in the design and manufacture of lighting control systems. Leading EU companies include Signify (NL), Osram (DE), Cooper (IE), Zumtobel Group (AT), all of whom offer **lighting management systems.** Major manufacturers of **intelligent cooling equipment** comprise Carrier (US), Daikin (JP) and Lennox International (US).[116]

Building energy management systems are vulnerable to **cyber-attacks**, including those facilitated by the use of open source and free network programs and code, and from embedded functionality, i.e. a functionality that is built-in the equipment but not activated (such as Wi-Fi or TCP/IP connectivity), which can be activated (possibly remotely) and be used to gain access to the device. In addition, backdoor or hidden functions allowing to gain control to the automation level could be inserted in BEMS components by malicious actors in the supply chain.

Table 1-20 Overall assessment for smart building and building automation supply chain

Overall assessment for smart building and building automation supply chain	
Strengths	**Weaknesses**
Europe has a strong position for many software and hardware categories related to smart buildings.	LED manufacturing requires arsenic and rare-earth elements, many of which are considered critical. US is leader in home energy management software. There is, however, a large number of new entrants in the market. Building energy management systems are vulnerable to cyber-attacks.

Heat pumps supply chain

Heat pumps are made of different types of metal. Copper or aluminium tubing, critical ingredients in many heat pump components, provide superior thermal properties and a positive influence on system efficiency. Various components in a heat pump will differ depending on the application, but usually they are comprised of stainless steel and other corrosion-resistant metals. Self-contained units that house the system will usually be encased in sheet metal that is protected from environmental conditions by a paint or powder coating. The encasements, the metal that envelopes most outdoor units, is made of galvanized sheet metal that uses a zinc coating to provide protection against corrosion.

Heat pumps may contain several raw materials categorised as critical. [117] Raw materials like vanadium and phosphorous are in some designations of steel used as alloying elements. These alloying elements are not included in this assessment as they are very difficult to quantify and more obvious choices are present such as:

- Printed circuit boards which may contain several critical materials such as gold, silver, palladium, antimony, bismuth, tantalum etc.[118];
- Compressor, tubing and heat exchangers which may contain copper;
- Wires which may contain copper.

Regarding processed material, frequently, plastic and other non-traditional materials are used to reduce weight and cost. The working fluid, the fluid that circulates through the air-conditioning system, is typically a liquid with strong thermodynamic characteristics like hydro-fluorocarbons (HFCs), chlorofluorocarbon (CFCs), hydrochlorofluorocarbons (HCFCs), ammonia, or water.

All heat pumps have four basic components: a pump, an evaporator, a condenser, and an expansion valve. All have a working fluid and an opposing fluid medium as well.

[116] Navigant Research. (2016). Advanced Energy Now 2016 Market Report. Available at: https://www.ourenergypolicy.org/wp-content/uploads/2016/03/AEN-2016-Market-Report.pdf
[117] Baijia Huang, Peter Martin Skov Hansen, Jan Viegand, Philippe Riviere, Hassane Asloune, et al. for DG ENER (2018). Air conditioners and comfort fans, Review of Regulation 206/2012 and 626/2011 Final report. Available at: https://hal-mines-paristech.archives-ouvertes.fr/hal-01796759/document
[118] Wrap. (2014). Techniques for recovering Printed Circuit Boards (PCBs): Final Report. Available at: https://archive.wrap.org.uk/sites/files/wrap/Techniques%20for%20recovering%20printed%20circuit%20boards,%20final.pdf

The European heat pump industry is a well-established economic sector and a world leader in highly efficient heat pump systems. The European heat pump sector is characterised by a few, mostly large corporations and a relatively small ecosystem with some innovative SMEs.

The European heat pump manufacturing sector comprises major world known names in heating (Nibe Industrier, BDR Thermea, Bosch Thermotechnology, Viessmann, etc.), but also global and major European refrigeration and air-conditioning players that have taken up positions in the heating market segment such as Japan's Daikin Industries and Mitsubishi Electric, France's CIAT.

Table 1-21 Overall assessment for heat pumps supply chain

Overall assessment for heat pumps supply chain	
Strengths	**Weaknesses**
The European heat pump industry is a well-established economic sector and a world leader in highly efficient heat pump systems.	Heat pumps contain several raw materials, such as copper, aluminium, zinc, that are mostly imported out of EU. Heat pumps contain printed circuit board, which are made of several critical raw materials.

Digital technologies supply chain - ICT, sensors, meters, control & cybersecurity

Digital technologies employed in the energy sector encompass a wide range of elements, from end-point systems and components for energy supply, transport and storage to consumption to the digital systems to ensure the reliable operation of electricity, gas and heat networks as well as of oil & gas production. There is no commonly agreed framework for categorising the different digital technology components, equipment and services employed in the energy sector. Nonetheless, the high level systems involving digital technologies for the energy sector can be divided between industrial control systems, end-point systems and communications networks. A number of components and equipment are used in ICS, end-point systems and communication networks, including programmable logical controllers (PLCs), remote transmission units, smart meters and sensors, and human-machine interfaces.

Vulnerabilities in raw and processed materials will become important if the EU develops its manufacturing capacity for digital technologies components. As currently the EU is highly dependent on foreign suppliers for 12 (categories of) **raw materials** used in digital technologies: boron, cobalt, gallium, germanium, graphite, indium, lithium, magnesium, PGMs, rare earth elements, silicon and tungsten. Rare earth elements have the highest supply risk, followed by magnesium, germanium and borates. The main suppliers for these materials are China (41%) and African countries (30%).

Digital technologies can be separated in hardware and software, although both are highly interrelated. The EU has a significant participation in the global production of digital components such as **embedded electronics, sensor systems or power electronics** (e.g. 23% for embedded electronics),but produces only 10% of the world's **electronic boards** and 9% of its **semiconductors**[119] **and microprocessors.**[120][121] Most of the main and contract manufacturers for **data servers and storage equipment** are non-EU companies, with most manufacturing capacity also located outside of the EU. Indeed, the EU is responsible for the production of around 4% of the global telecommunication equipment manufacture.[122]

A study for DG CONNECT indicates that the EU is a leading player in **industrial** (20% share of global production), **automotive** (27%) and **embedded electronics** (23%).[123] On industrial electronics, it is a particular leader on factory automation (19% of the global production in 2016), test and measuring (30%), power applications (22%) and transportation (33%). It also has an important share (16%) of the global production of electronic components, materials and tools. The EU is a leading player in the **programmable logic controllers** (PLC) market. The EU27 market for **electricity grid monitoring, sensors, and connected IoT devices** is made up almost entirely of distribution equipment, especially distribution transformer sensors and substation automation,

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[119] This includes all types of finished semiconductor components employed in e.g. consumer, industrial, aerospace, and automotive electronics, covering from large power transistors to microprocessors and small semiconductor components employed in electronics boards.
[120] European Commission. (2020). Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study.
[121] European Political Strategy Centre. (2019). Rethinking Strategic Autonomy in the Digital Age. Available at: https://op.europa.eu/nl/publication-detail/-/publication/889dd7b7-0cde-11ea-8c1f-01aa75ed71a1/language-en/format-PDF/source-118064052
[122] DECISION for DG CONNECT. (2020). Study on the Electronics Ecosystem. Available at: https://op.europa.eu/nl/publication-detail/-/publication/8e442825-493f-11ea-b81b-01aa75ed71a1/language-en
[123] Ibid.

estimated to surpass 1 100 million EUR in 2020. Major manufacturers are Hitachi (JP), ABB (CH), Siemens (DE), Itron (US) and Schneider Electric (FR)[124].

Regarding various **energy management and industrial control systems**, Europe made in 2018 152 million EUR of public and private investments for managing virtual power plants (VPPs), against 446.3 million EUR for the rest of the world (RoW). Major VPP software suppliers are ABB (CH), Next Kraftwerke (DE), Centrica (UK) and Schneider Electric (DE). [125] For **distributed energy resources (DER) management systems** European investments amount to 65 million EUR (against 102.3 million EUR for the RoW). Major DER management system suppliers are GE (US), Schneider Electric (FR), Siemens (DE), ABB (CH) and OSI (US). [126] The EU investments in **DER analytics software** are more modest, at 37.8 million EUR (against 140.1 million EUR for the RoW). The market for DER analytics is more fragmented, with the major suppliers being Landis+Gyr (CH), Itron (US), Siemens (DE), Oracle (US) and GE (US). Hence, EU investments in DER management systems and VPP software are particularly important compared to the RoW.[127] The EU has the highest penetration of **advanced distribution management systems (ADMS)** in the world, with higher rates of deployment observed in Western European network operators. The market is concentrated, with the main suppliers being GE (US), Schneider Electric (FR), Oracle (US), Siemens (DE), ABB (CH) and ACS-Indra (ES).

Foreign ownership of digital technologies companies is also a relevant question gaining increased attention. While China has a strong focus on the sector, the US and Canada have a more important foothold on relevant EU sectors, owning around 45% of EU electronic components manufacturing assets and 41% for communication equipment manufacturing assets. Around 54% of the assets in the EU for the manufacture of computer, electronic and optical products in 2016 were foreign-owned.[128]

In addition to the dependence on foreign suppliers of digital technologies, the energy sector may also be vulnerable to cyber threats. Out of the various cybersecurity issues which should be considered, the ones related to supply chains comprise the:[129]

- **Integrity of digital technology components and their supply chain, i.e.** [130]**:** unintentional vulnerabilities may not be identified and corrected on time (due to e.g. a lack of appropriate supplier management and agreed processes with suppliers to identify and mitigate such vulnerabilities), or backdoors or hidden functions may be embedded in digital components used in the energy sector or to provide services to it. Zero-day vulnerabilities or backdoors can be employed later on by malicious actors to compromise (segments of) the energy sector;
- **Outsourcing of infrastructures and services**: 3rd party data services and telecommunication networks may have lower reliability requirements, and be a target of cyber attacks which can then disrupt the energy sector or provide a point of entry to energy companies.

The integrity of digital energy technologies supply chains and the outsourcing of digital infrastructure and services are concrete vulnerabilities of the EU energy system. The importance of cyber vulnerabilities of digital technologies depends on the energy supply chain they are employed and the number of devices deployed. Electricity and gas systems have been highlighted as strategic due to the systemic impact of disruptions. Nuclear energy generators are also strategic from a safety perspective.[131] However, while isolated compromised end-point devices such as home routers may not impact the overall energy system, as these end-point devices may employ common hardware, software and protocols, they may be vulnerable to attacks affecting thousands or more devices, leading to a significant impact to ICT or energy systems. Hence, systemic risks arise not only from vulnerable critical, centralised components but also vulnerable distributed devices whose systemic disruption may have large-scale impacts. [132]

There is a need for maintaining software systems up-to-date, conducting vulnerability tests (e.g. to detect potential system devices which may be visible on public networks) and managing supply chain

[124] European Commission. (2020). Clean Energy Transition – Technologies and Innovations. SWD(2020) 953.
[125] Ibid.
[126] Ibid.
[127] Ibid.
[128] European Commission. (2019). Foreign Direct Investment in the EU. SWD(2019) 108.
[129] NIS Cooperation Group. (2019). EU-wide Cybersecurity legislation: Report on the implementation of the EU rules in the energy sector. Available at: https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=62799
[130] Public-Private Analytic Exchange Program. (2017). Supply Chain Risks of SCADA/Industrial Control Systems in the Electricity Sector: Recognizing Risks and Recommended Mitigation Actions.
[131] NIS Cooperation Group. (2019). EU-wide Cybersecurity legislation: Report on the implementation of the EU rules in the energy sector. Available at: https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=62799
[132] European Political Strategy Centre. (2019). Rethinking Strategic Autonomy in the Digital Age. Available at: https://op.europa.eu/nl/publication-detail/-/publication/889dd7b7-0cde-11ea-8c1f-01aa75ed71a1/language-en/format-PDF/source-118064052

relationships so hardware, software and services suppliers promptly identify, communicate and address vulnerabilities and security breaches. Reliance on domestic and foreign digital technologies suppliers can effectively expose critical EU digital and energy infrastructure to cyber attacks[133], if there is not an effective management system to minimise risks that hardware and software employed in the EU energy sector are compromised due to e.g. zero-day vulnerabilities or backdoors.

Table 1-22 Overall assessment for digital technologies supply chain

Overall assessment for digital technologies supply chain	
Strengths	**Weaknesses**
	The EU is highly dependent on foreign suppliers for 12 (categories of) raw materials used in digital technologies
The EU has a significant participation in the global production of embedded electronics, sensor systems and power electronics.	The EU produces only 10% of the world's electronic boards and 9% of its semiconductors and microprocessors.
EU is a leading player in industrial (20% share of global production), automotive (27%) and embedded electronics (23%). It also leads in the programmable logic controllers (PLC) market.	Most of the main and contract manufacturers for data servers and storage equipment are non-EU companies, with most manufacturing capacity also located outside of the EU.
The EU has the highest penetration of advanced distribution management systems (ADMS) in the world.	Around 54% of the assets in the EU for the manufacture of computer, electronic and optical products in 2016 were foreign-owned.
	The integrity of digital energy technologies supply chains and the outsourcing of digital infrastructure and services are concrete vulnerabilities of the EU energy system.

1.2.3. *Validation of critical supply* chains

Based on the assessment in chapter 1 to identify strategic technologies and the vulnerability analysis above, we conclude that all strategic supply chains analysed except for hydropower, heat pumps and biomass gasifiers & gas turbines are subject to important vulnerabilities (at least one supply chain stage block in Table 1-9 is classified with the red colour).

Based on the definition proposed in our methodology section, strategic supply chains that exhibit vulnerabilities are considered critical. Hence, the analysis in chapter 2 and 3 focuses these critical supply chains:

- Wind energy – onshore/offshore
- Solar PV
- Nuclear fission
- Hydrogen production, storage and end-use
- Gas infrastructure
- Electricity networks
- Batteries
- Smart buildings and building automation
- Digital technologies

[133] A number of other cybersecurity aspects beyond supply chains-related ones should be considered but are not analysed here. The Directive on Security of Network and Information Systems (EU) 2016/1148 provides cybersecurity provisions applying to multiple sectors, including the energy sector. See also European Commission (2019) EU-wide Cybersecurity legislation: Report on the implementation of the EU rules in the energy sector.

Figure 1-8 Supply chain analysis process to select the critical supply chains

Hydropower, heat pumps and biomass gasifiers & gas turbines remain highly strategic to the EU energy system, but were not included in the list of critical supply chains due to the fact that no major vulnerabilities in the supply chains were identified based on the assessment above. The selection of critical supply chains does not mean the mentioned supply chains are not relevant. On the contrary, some of these technologies may play an important role and increase the resilience of the energy system (e.g. hydro offering black start service to the electricity system in the case of a black out).

In addition, other energy technology supply chains such as district heating and cooling, liquid biofuels or carbon capture and storage may also be highly strategic to certain sub-sectors (e.g. for decarbonising heavy-duty freight or aviation in the case of biofuels), but, based on the proposed methodology in this study, were not classified as highly strategic.

Table 1-23 Overview of the vulnerability of energy technologies supply chain stages, with critical elements indicated

Strategic supply chains	Raw & Processed Materials	Manufacturing & Assembly	O&M
Wind	Cu, **Dy**, **Nd**; electrical steel	Permanent magnets	Vulnerability to cyber attacks due to increased digitalisation Availability of installation vessels for offshore wind
Solar PV	**B,** Cu, **Ga, Ge**, **In**, Se, **Si**, Te	PV cells and modules	Potential for vulnerability to cyber attacks due to remotely controlled inverters
Hydropower and pumped hydro storage			
Nuclear fission	Ar, Cr, N, Zn; Ni-Cr-Fe alloys	Nuclear-grade certified suppliers (primary circuits, rods and other components/services for the nuclear island)	Certified service providers
Biomass gasifiers and Gas Turbines		Heavy duty turbine blades and vanes castings supplied mostly from outside of Europe.	O&M services subject to cybersecurity risk
H_2 production / storage / use	**PGMs (Pt, Pd, Ru, Rh, Ir), REEs , Ti** CFC, (PFSA)	Previously HFC stack assembly	
Gas infrastructure		Ball valves, filters, and purifiers	Cyber security of control systems / 3rd party service providers
Electricity networks	Al**,** Cu, **Mg**, **Si**; electrical steel		Cyber security of control systems / 3rd party service providers
Batteries	Al**, Co, Li, Nb,** Ni**, Si**, **Ti, graphite**	Li-ion cells, cathode, anode, electrolyte, separator	
Smart buildings	**B, Co, Ga, Ge, In, Li, Mg, graphite, PGMs, REEs, Si, W**	Home energy management systems	Cyber security of home/building energy management systems and decentralised devices
Heat pumps			
Digital technologies	**B, Co, Ga, Ge, In, Li, Mg, graphite, PGMS, REEs, Si, W**	Electronic boards, semiconductors and processors Servers and data storage equipment	Related to cyber-security of digital technologies use in other supply chains

Legend:
red – supply chain stage with a few vulnerable elements / with high risk vulnerabilities;
yellow - supply chain stage with one to a couple of elements identified as vulnerable;
green – supply chain stage without vulnerable elements.
bold *– critical raw materials (CRMs) based on EC list for 2020; Note that the CRMs on the EC list are based on considering their use across the economy as a whole not only the energy sector. In addition, the criticality definition used by the JRC differs from the one used here, hence some materials identified as vulnerable for the energy sector are not part of the CRM list.*

2. ASSESSMENT OF CURRENT AND POTENTIAL PROBLEMS FOR CRITICAL SUPPLY CHAINS

Section 1 of the report has provided an assessment of the critical energy technology supply chains, and have identified the most vulnerable components and elements for each of these supply chains. The following section explores how different threats could exacerbate these vulnerabilities, and investigates the root causes leading to these vulnerabilities.

2.1. Inventory of problems resulting from COVID-19

Main findings of section 2.1

- EU energy technology supply chains have shown to be resilient to the COVID-19 crisis
  - Most chains identified solutions to the problems faced and many businesses already had business continuity plans in place;
  - The weaknesses of the energy technology supply chains as identified in Section 1.2 are sometimes passed on as added challenges faced during the COVID-19 pandemic. For example, these are observed in the nuclear sector, which has been facing shortages in qualified suppliers; Battery manufacturing, which has been reliant on imports for cobalt, with low substitutability of the material; Wind turbine and Solar PV manufacturing, which rely heavily on imports for raw materials etc.
- While generally resilient, there were many impacts nonetheless for all chains;
  - The implemented closure of borders and travel restrictions disrupted the movement of goods and skilled labour to carry out specialised works in operation and maintenance;
  - Social distancing measures created challenges in the flow of products and led to price increases, which have affected the operating cost of some supply chains, e.g. gas infrastructure;
  - Sectors which were classified as essential managed to continue operations, but still had to take significant measures to cope with the challenges faced.
- Intra-EU difficulties were often more important than manufacturing and logistics challenges in non-EU countries;
  - China and other Asian countries, which are important EU suppliers, addressed the pandemic early on and limited the impacts to the supply chain (to various degrees)
- Interviewees highlighted that global supply chains (i.e. highly integrated and open internationally) provide multiple advantages including supply diversification and access to global markets;
- Other factors such as economic downturn, cash flow difficulties and lack of firm policy signals are pivotal and have negatively impacted supply chains. These are important aspects, but are out of the scope of the study.

This section focuses on the analysis of the problems arising in energy technology supply chains due to COVID-19.

The development of energy projects in the EU and their operation will be affected by other important impacts of COVID-19 which may not be supply chain-related. Examples of these aspects which may be very important to the supply chains assessed in this study, but that are considered as out of scope for this study are:

- Difficulties in financing of (renewable) energy projects due to changes in forecasted energy demand and increased risk perception by financing institutions and other investors;
- Changes in government energy & climate policies, especially the reduced level of support to renewable energy due to budgetary constraints;
- Cash flow problems and risk of bankruptcy of energy technology suppliers of products and service, due to the economic crisis and COVID-19-related measures such as lockdowns.

The COVID-19 pandemic has been a significant stress test to the EU energy system. The resilience of the European energy system has also proven by the fact that there has been no COVID-19-related disruption to energy supply in the EU since the onset of the pandemic. This underlines the robustness of the measures that were already in place[134], including a well-designed and functioning internal

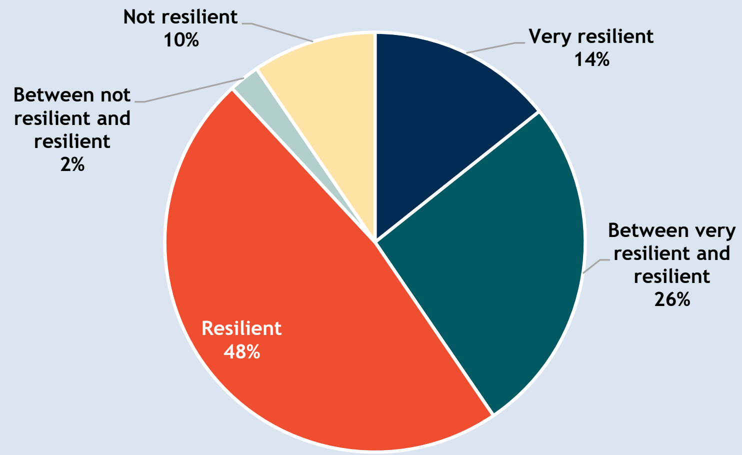
[134] Council of the European Union. (2020). Council conclusions on the response to the COVID-19 pandemic in the EU energy sector. Available at: https://data.consilium.europa.eu/doc/document/ST-9133-2020-INIT/en/pdf

energy market[135] and critical energy infrastructure measures, as well as emergency measures agreed at the EU level to assure the cross-border flows of products and essential services, which ensured that energy was available where it was needed. The strong resilience of the EU energy system in a pandemic situation is also supported by most of the respondents to the study survey (see Textbox 2-1). Nonetheless, the dynamics that have arisen as a result of the COVID-19 pandemic have led to issues for the energy technology supply chains in the EU, in various degrees.

Textbox 2-1 Opinions of survey respondents' on the resilience of the EU energy system against pandemics

The majority of the survey respondents agree that the EU energy system is resilient to pandemics, with 88% rating it as between resilient to very resilient. Some respondents commented that the performance of the energy system during the COVID-19 pandemic is proof of its resilience.

Figure 2-1 Survey answers to the resilience of the EU energy system against pandemics ($n_{respondents}$ = 42)



2.1.1. Key observations on the impacts of COVID-19 on energy supply chains

An examination of problems experienced by the EU energy technology supply chains since the onset of the COVID-19 crisis until November 2020 was carried out. This formed the basis for further analysis carried out to identify the main drivers from the COVID-19 crisis resulting in impacts to the energy technology supply chains due to specific vulnerabilities.

In May 2021, the European Commission updated its industrial strategy[136] to ensure the EU industrial ambition takes account of the new circumstances following the COVID-19 crisis, while ensuring European industry can lead the way in transitioning to a green, digital and resilient economy. The updated industrial strategy reaffirms the priorities set out in March 2020, while using important lessons learned to ensure the recovery of Europe's industry and economy.

According to this update, for the entire EU industry, the COVID-19 crisis has strongly affected the EU economy and exposed the interdependence of global value chains and demonstrated the critical role of a globally integrated and well-functioning single market. The impact of the crisis varies across different ecosystems and companies, but the key issues it highlighted are

- closed borders restricting the free movement of goods and services
- interrupted global supply chains affecting availability of essential products
- disruption of demand

To address these issues, the updated strategy proposes new measures that focus in particular on

- strengthening the resilience of the single market
- supporting Europe's open strategic autonomy by addressing strategic dependencies
- accelerating the twin transitions to a green and digital economy

[135] European Commission. (April 27, 2020). In focus: Energy security in the EU. Available at: https://ec.europa.eu/info/news/focus-energy-security-eu-2020-avr-27_en
[136] European Commission. (n.d.). European Industrial strategy. Available at: https://ec.europa.eu/growth/industry/policy_en

Our analysis supports the finding that in general, EU energy technology supply chains have shown to be resilient. The analysis and interviews indicate that most supply chains have identified solutions to address the problems faced. The crisis has also shown that many businesses already had business continuity plans in place. The crisis has been an opportunity to test and improve these plans. Exceptions exist, for example, where the digital technologies supply chain observed delays in the majority of deliveries from EU Member States as well as from the US and the main Asian suppliers, months into the pandemic (according to a survey by DIGITALEUROPE of companies involved in software and IT services, ICT hardware manufacturing, wholesale and retail, and other related areas).[137] In the present study, digital technologies include both hardware (from semiconductors to printed circuit boards and the embedded and stand-alone electronic products employing them) as well as software for information technology (IT) and operational technology (OT). Other technology supply chains were already experiencing challenges prior to COVID-19, for example, the availability of suppliers certified suppliers to provide nuclear-grade services, structures and components in the nuclear sector has been an important challenge for some time now.

There were many impacts nonetheless for all supply chains. During the COVID-19 pandemic, the disruptions experienced upstream in the energy technology supply chains have had cascading impacts on downstream stages. For example, the disruptions in the supply of materials and components due to the suspension of production and the disruptions in the logistics sector and transportation networks due to business restrictions have resulted in supply bottlenecks to the construction and installation stage. The closure of borders and travel restrictions that have been implemented disrupted the movement of skilled labour to carry out specialised works in operation and maintenance. Additionally, the social distancing measures implemented during COVID-19 have not only created challenges in the flow of products, but have also led to price increases in products and other services such as transportation, which have affected the operating cost of some energy technology supply chains. For example, a gas TSO in a Western European Member State has observed that suppliers have started incorporating the additional costs arising from COVID-19 in their new price quotes. However, these impacts were not specific to the energy technology supply chains, but affected all economic sectors in general.

Intra-EU difficulties were often more important than manufacturing and logistics challenges in non-EU countries. China and other Asian countries which are important EU suppliers addressed the pandemic early on and limited the impacts to the supply chain (to various degrees). But measures such as closure of intra-EU borders and lockdowns in the EU still impacted supply chains. Sectors which were classified as essential managed to continue operations, but still had to take significant measures for e.g. hygiene and also incurred administrative cost due to the lack of information for example on requirements for authorising suppliers and the speed with which measures changed. This highlights the risk of supplier concentration, which exacerbates the impacts felt by the supply chains during the pandemic. **Interviewees have also highlighted that global supply chains provide multiple advantages including supply diversification and access to global markets.** Many EU business are not only dependent on imports but also on exports.

Other factors such as economic downturn, cash flow difficulties and lack of firm policy signals are pivotal and have negatively impacted supply chains. These need to be highlighted but are, however, out of the scope of the study.

2.1.2. Impacts of COVID-19 on energy technology supply chains

The section below further describes the individual impacts of COVID-19 on the EU energy technology supply chains. The key impacts of COVID-19 on the energy supply chains within the EU are summarised in Table 2-1 below. Further information on the analysis per supply chain can be found in Annex B.

Disruption in trade of goods

The COVID-19 pandemic has led to issues arising from social distancing and travel restriction measures that were put in place. In a pandemic situation that has spread worldwide, the EU energy supply chains are not only faced with issues with uncertain materials and components supply from third countries but also from intra-EU countries as a result of a reduction or complete halt in the production capacities of factories due to social distancing measures in place within and beyond the EU. In addition, flight restrictions and tighter border controls that were put in place to control the pandemic has also led to an increase in logistics costs, and delays in delivery of goods within the energy technology supply chains.

[137] DIGITALEUROPE. (2020). Pan-European survey on the impact of COVID-19 on the digital industry. Available at: https://www.digitaleurope.org/resources/pan-european-survey-on-the-impact-of-COVID-19-on-the-digital-industry/

Disruption of supply of skilled labour

Not only is the flow of material supplies affected during the global pandemic, but it has also limited the free movement of skilled workers to carry out specialised works within the energy supply chains due to border restrictions and travel bans intra-EU and with third countries as they may not necessarily classify as 'essential workers'. This has an impact on the different stages of the energy supply chains. The access of skilled workers to construct or install new energy technologies are restricted as a result of social distancing measures, which was experienced by the solar PV and wind supply chains. Operations and maintenance works also had to be adjusted or rescheduled as the social distancing measures restricted access to worksites of solar PV, wind, nuclear power plants, gas and electricity networks. In addition, travel restrictions within the EU had also resulted in a shortage of skilled labour to perform specialised operations and maintenance works was also experienced by multiple energy supply chains. Beyond the energy supply chains, delays in the administration process by local authorities or services also had an impact on the energy supply chains, for example in obtaining permits, arranging for inspections and billing of customers.

Delays in the timeline of new installations and scheduled maintenance works

The social distancing measures have also led to delays in the construction and installation of new project sites, affecting energy supply chains of solar PV and new grid connections for example. In some cases, tenders and commissioned projects were also cancelled, including solar PV and wind energy projects. The effects of COVID-19 on the construction and installation supply chain stage differs across different energy technologies. For example, newly installed solar power in the EU managed to achieve a positive increase by 11% to 18.2 GW in 2020[138], although new wind capacity decreased by 6% as compared to 2019 due to the impact of the COVID-19 pandemic on the onshore wind sector[139].

Further, many of the maintenance scheduled had to be delayed and rescheduled. For example, there were delays in the maintenance of electricity transmission networks, smart building technologies and solar PV, as well as adjustments to the shutdown, refuelling and maintenance of nuclear plants. The rescheduling of maintenance works raises concerns of the negative impact it might have on the security of energy supplies in the winter.

Delays in logistics and administrative processes

The energy supply chains were also impacted by the disruptions beyond the energy supply chains, for example, due to the delays in the logistics sector and local governments. Air freight frequencies were reduced in the initial period of the COVID-19 pandemic due to air travel restrictions. Delays in administrative processes of local governments due to the lack of digitalization of processes also led to delays in new construction and installation works, as well as the commissioning of completed projects, presenting additional price and time costs to investments.

Shortage of Personal Protection Equipment (PPE)

Difficulties in obtaining sufficient PPE, including masks and gloves, to facilitate a safe working environment for their staff were also reported by the electricity sector. The need to provide PPE and the setup of a safe working environment at work sites, such as arranging for transport, providing increased sanitation etc., also increase the operating costs experienced across the different supply chain stages, including manufacturing, construction and installation, and operations and maintenance stages of the energy supply chains.

Short-term cash-flow issues and uncertainty in investment outlook for clean energy technologies

Many energy companies are facing default payments from customers who may be financially affected by the COVID-19 situation. EU Member States have put in place measures to protect the consumers as well as businesses, but to different degrees. In addition, the decrease in electricity prices, as a result of reduced energy demand, has further weakened the financial situation of energy companies. The European Central Bank expects the EU economic output to face an 8% downturn in 2020, as a result of the COVID-19 pandemic[140], rebounding with a 5% growth in 2021. The reduced economic activity further leads to cash flow difficulties in suppliers in the energy technology supply chains. The wind industry and the hydrogen technology industry also highlighted that the impact of COVID-19

[138] SolarPower Europe. (2020). EU Market Outlook for Solar Power, 2020-2024. Available at: https://www.solarpowereurope.org/european-market-outlook-for-solar-power-(2020-2024)
[139] WindEurope. (2021). Wind energy in Europe 2020 Statistics and the outlook for 2021-2025. Available at: https://windeurope.org/data-and-analysis/product/wind-energy-in-europe-in-2020-trends-and-statistics/
[140] European Central Bank. (2020). Past macro-economic projection ranges – September 2020. https://www.ecb.europa.eu/mopo/strategy/ecana/html/table.en.html

may be uneven, as investment capital for smaller projects are likely to be more affected than larger projects.

In anticipation of the period of economic recession, the IEA[141] had also forecasted a decrease in the investments in clean energy technologies in 2020. The current low prices of electricity, uncertainty in the demand for energy, as well as in the political will of national governments to pursue the clean energy agenda in post-COVID-19 recovery have an impact on investors' confidence in the clean energy technologies. Notwithstanding, investments in clean energy technologies can expect to grow in the EU. Despite the challenges of COVID-19 in 2020, a record amount of €26.3 billion was invested in offshore wind, financing 7.1 GW of new capacity. On 8 July 2020, a Hydrogen Strategy was adopted by the European Commission where a roadmap to scale up renewable hydrogen supply and demand has been laid out, up to 2050. This is expected to stimulate significant investments amounting to billions of euros in electrolysers, hydrogen transport, distribution and storage and refuelling stations. In addition, the EU has also established a Recovery and Resilience Facility which avails €672.5 billion in loans and grants to support Member States to prepare for a sustainable economy post COVID-19. The IEA has also reported that Europe is posed to be a leading developer of renewable energy projects in 2021, driven by the completion of delayed projects, previous auctions, the EU recovery fund and EU and national policies.[142]

In some Member States, some investors have perceived an increased uncertainty regarding policy signals and political commitment to renewable energy, due to budgetary constraints and the risk to focus on economic recovery rather than on decarbonisation and renewable energy targets[143]. In addition to the delays of new construction of production facilities, other delays, such as the non realization of new grid connections and delays in the roll-out of smart meters also affect the pace of the clean energy transition.

While these issues were frequently cited by the renewable energy industry and other energy businesses, they are not analysed in further detail, as the scope of the study focuses on the critical energy supply chains, and less on the macro-economic impacts of the COVID-19 crisis.

[141] IEA. (2020. European Union 2020: Energy Policy Review. Available at: https://www.iea.org/reports/european-union-2020

[142] IEA. (2020). Renewables 2020 – Analysis and forecast to 2025.Available at: https://www.iea.org/reports/renewables-2020

[143] AURES II. (2020). Policy Brief, May 2020: Impact of COVID-19 on Renewable Energy Actions. Available at: http://aures2project.eu/wp-content/uploads/2020/05/AURES_II_Policy_Brief_Covid-19.pdf

Table 2-1 Impacts of COVID-19 on EU energy technology supply chains

Key impacts of COVID-19	Summary	Main supply chain stages impacted	Supply chains affected (non-exhaustive)	Root cause vulnerability	Possible mitigation measures
Disruption in **trade flows** from **third** countries	Social distancing measures were taken globally, for example by US, Asia, and especially China resulted in a disruption of goods supply to the EU. For example, social distancing measures were implemented in China in mid-January 2020 to control the spread of the COVID-19 pandemic. The measures implemented in China had an impact on production, and EU trade with China fell in February and March 2020. The delivery of ICT components experienced delays in more than 40% of orders from China alone. The issues in supply chains in China and India also created uncertainties in the supply of materials for the construction in gas networks. Manufacturers for smart building supply chains also faced disruptions in the supply chains and increased logistic costs at the onset of COVID-19 in Europe. The manufacturing of wind turbines in EU is also susceptible to disruptions due to the reliance of goods from third countries. On the other hand, in the Solar PV sector, Sweden mentioned that the trade disruptions did not affect the industry as there are diverse suppliers to choose from.	• Raw & processed Materials • Construction and Installation (due to upstream effects) • Manufacturing • Operations & Maintenance (due to upstream effects)	Solar PV, Digital technologies, Smart Buildings, Gas infrastructure, Wind	Dependencies on third country suppliers; Supplier concentration	• Diversification of sources (countries/regions) • Set minimum production capacity required within the EU for critical supplies (including PPE etc.) • Identifying and stockpiling critical materials within the EU • Promote parts exchange between sector companies (especially network operators)
Disruption in the **trade flows** from **EU Member States**	Intra-EU border closures and restrictions also had an impact on the flow of goods. ICT components saw 74% of deliveries affected by the border control measures put in place. In addition, halts in sectors that were not considered as 'essential' also led to a significant reduction in the supply of equipment and components within the EU. For example, in April 2020 the heating, ventilation and AC production capacity was reduced by at least 50% within the EU. WindEurope also reported in April 2020, on the closure of 18 wind turbine manufacturing sites in Spain and Italy. Although several Member States added the manufacturing of electric components in the list of essential activities to facilitate trade flows, the electricity networks and other essential sectors remained affected. This was due to reasons including unclear procedures for obtaining authorisations for suppliers, and in the fast-changing measures that were implemented as they adapted to the evolving pandemic situation.	• Raw & Processed Materials • Manufacturing • Construction and installation • Operations and maintenance	Digital technologies, Smart buildings, Wind, Gas infrastructure	Dependencies on non-local suppliers and oligopolies; Supplier concentration	• Agree on a list of energy services, as well as the energy professionals, which are considered as 'critical' in times of crises • Coordinate on a business continuity plan within intra-EU borders to facilitate smooth operations in times of crises • Diversification of sources within the EU to spread risks

Key impacts of COVID-19	Summary	Main supply chain stages impacted	Supply chains affected (non-exhaustive)	Root cause vulnerability	Possible mitigation measures
Disruption in the flow of **staff and contractors** from **EU Member States**	Against the backdrop of the need to limit the spread of COVID-19, Member States implemented a temporary restriction on non-essential travel within the EU, to various extents. This has led to delays in construction and O&M , restricting access to installers and other personnel, as this scope of work does not fall under the category of 'essential workers'. For example hydropower, where suppliers of O&M services from non-local sources also faced difficulty to carry out their contracts due to travel bans. A lack of skilled workforce to perform operation and maintenance works was also observed in the wind and nuclear energy sectors. Some sectors (gas networks, especially nuclear) were also affected as quality inspectors could not conduct inspections in the suppliers' site. This had been addressed to various extents by contracting local inspectors or remote inspections.	• Construction and installation • Operations and maintenance	Solar PV, Wind, Gas infrastructure, Nuclear	Dependence on physical presence	• Agree on a list of energy services, as well as the energy professionals, which are considered as 'critical' • Promote remote inspections • Harmonise procedures for authorising 'essential' suppliers and requirements for travel, testing • Providing a central point of information regarding COVID-19 measures and procedures to businesses
Restriction of access for **staff and contractors** at new and existing, work sites	Project delays were also reported in new installations, including solar PV and new grid connections. Depending on the country and whether sectors were classified as essential, existing and/or new projects were affected. Generally, administrative work could be done remotely, but construction work requires by nature physical presence. Many of the maintenance scheduled, such as planned outages in the electricity sector or refuelling of nuclear power plants, had to be delayed/altered. The rescheduling of outages raised concerns of having a negative impact of the security of electricity supply in the winter, although gas and electricity TSOs have finally not identified significant supply risks. Initial delays were also reported for some maintenance works in gas networks in France.	• Construction and installation • Operations and Maintenance	Solar PV, Electricity networks, Wind, Nuclear Fission, Gas infrastructure	Dependence on physical presence	• Reskilling of staff to on business continuity plans to cope with crises events, such as adapting to work in shifts • Digitalization of operations, with enhanced cybersecurity to facilitate remote work • Adaptation to home office culture, online trainings, including training for staff to detect phishing emails, removing malware, and restricting the use of software were implemented
Longer delivery time and costs due to **customs delays and other logistical issues**	Air travel restrictions and air freight market disruptions that were part of the global measures to control the pandemic had an impact on the delivery of goods. Maritime and intra-EU transportation costs were also affected. Deliveries to EU regions with high infections were affected.	• Raw & processed materials • Construction and installation (due to upstream effects)	Solar PV, Electricity networks	Dependencies on third country suppliers; Dependence on physical presence	• Review of processes and digitalizing processes where possible in logistical processes

Key impacts of COVID-19	Summary	Main supply chain stages impacted	Supply chains affected (non-exhaustive)	Root cause vulnerability	Possible mitigation measures
Delays in **public administration processes**	Delays in administrative processes as a result of the limitations faced by remote home and closure of public offices also impacted supply chains. For example, delays were reported for obtaining permits to start work. In Belgium, delayed procedures and inspections resulted in some companies not being able to benefit from the Feed-In Tariff of Q1 2020, which is higher than Q2 2020. In Germany, some administrative processes were not digitalised and thus permits for gas network projects could not be requested.	• Construction and installation • Commissioning	Solar PV, Gas infrastructure, Wind	Dependence on physical presence	• Digitalization of public administration processes, with enhanced cybersecurity to facilitate remote work
Shortage of **Personal Protection Equipment (PPE)**	The COVID-19 pandemic resulted in a worldwide shortage of Personal Protection Equipment (PPE). China is a major producer of face masks, and in January and February kept the stocks within the country to cope with the COVID-19 situation. Although it did not impose an export ban on face masks, exports of face masks only resumed in March 2020. There were also bottlenecks in the supply of raw materials to produce face masks due to export bans, or hoarding of these materials in the source countries[144]. The lack of access to PPE such as face masks and gloves also lead to difficulties in continuing operations and maintenance works in the energy sector. The lack of PPE was the most common shortage affecting the EU energy technology supply chains. Some sectors such as nuclear energy had PPE stocks as part of their business continuity plans.	• Raw and processed materials • Manufacturing • Construction and installation • Operations and maintenance	Solar PV, Electricity networks, Gas infrastructure, Nuclear energy	Dependencies on third country suppliers; Limited capabilities of critical supply chains; Lack of stocks	• *European Commission adopted a recommendation to temporary relax the rule on requiring PPE to bear the CE-markings, to increase the production capacities within the EU[145] • *Stockpiling a minimum quantity of PPE within EU

*These measures have already been implemented.

[144] OECD. (2020). The face mask global value chain in the COVID-19 outbreak: Evidence and policy lessons. Available at: http://www.oecd.org.vu-nl.idm.oclc.org/coronavirus/policy-responses/the-face-mask-global-value-chain-in-the-COVID-19-outbreak-evidence-and-policy-lessons-a4df866d/#endnotea0z19

[145] While production capacities have increased as a response to COVID-19, most are likely to be here only for the shorter-term. The outlook for the face masks market is rather unstable, as there is no certainty in the demand for face masks post COVID-19. Such demand may come, to a larger extent, from building stockpiles at the national and EU levels, and lesser from general consumers. Nonetheless, the increased production capacities of some bigger players may be here to stay for the longer term. For example, companies such as Innovatec, Mondi and Sandler are likely to sustain the increase in production capacities.

2.2. Potential problems from three other threat scenarios

This section identifies potential vulnerabilities of the critical energy technology supply chains, in three plausible threat scenarios, in addition to persistent pandemics. The considered scenarios are *extreme weather events, geo-political uncertainty and tensions, and cyber threats.*

Main findings of section 2.2

- Stakeholders often have not considered nor assessed the impact of supply chain-related cyber-attacks, extreme weather events or geo-political tensions on their supply chains;
- EU's reliance on imports for raw and processed materials, and supplier concentration (in both EU and non-EU countries) are the key root causes of the vulnerabilities in the energy technology supply chains assessed across all four threat scenarios. These two factors are also weaknesses that have been identified in the energy technology supply chains as discussed in Section 1.2;
- Important hazards to the EU supply chains comprise border closures and manufacturing constraints in the EU or third countries due to persistent pandemics, cyber threats, and export restrictions by trade partners affecting elements with a high external dependency and supplier concentration;
- Coordinated and integrated emergency preparedness and disaster recovery plans across the different energy technology supply chains within the EU should be improved, as per the EU's own evaluations;
- The threat scenarios present different risk levels to the different energy technology supply chains and to the different supply chain stages, and would require different levels of granularity and prescription of mitigation measures, as per the EU's own evaluations.

On extreme weather conditions

- The increase in the frequency and intensity of weather extreme events can amplify disruptions to the energy technologies due to supplier concentration;
- While the effects of most extreme weather events may only briefly affect supply chains, larger-scale ones may have significant impacts.

On cyber threats

- Attacks to energy utilities, oil and natural gas, and manufacturing sectors globally are increasing. The accelerated adoption of digital technologies and Internet of Things (IoT) devices compounds the risk exposure of the energy technologies supply chains;
- Cybersecurity is most often considered by stakeholders, but more efforts are placed in protection against direct attacks, such as phishing attacks, than addressing cyber vulnerabilities related to the broader supply chains, such as mitigation of third-party cyber risks (such as the SolarWinds incident – see Textbox 2-2) and/or diversification of suppliers;
- Cybersecurity measures typically focus more on risk mitigation measures for Information Technology (IT) and less on Operational Technology (OT), nor on the increasing interactions between them. However, the latter is gaining increasing attention;
- Currently, the EU is already taking active measures to mitigate such risks. For example, through the standardisation of cybersecurity certification for ICT products, processes and services in general. In addition, the European Committee for Standardization (CEN), and the European Committee for Electrotechnical Standardization (CENELEC) is adopting European-level standards focusing on OT and IT separately.[146] In addition, the proposal to revise the Directive on security and network and information systems (NIS 2) has also been adopted in December 2020.

On geo-political uncertainty and tension

- The EU dependence on certain regions for the supply of materials, equipment and components increases the risk of supply chain disruptions.
- The EU is currently still at significant risk of experiencing supply disruptions from geo-political uncertainty and tension. Moreover, the EU is highly dependent on some countries and regions for components and equipment.
- The EU has taken various measures to mitigate the risks associated with this threat scenario. This includes:

[146] EN EIC 62443 series for OT, and EN ISO/IEC 27000 series for IT.
https://joinup.ec.europa.eu/collection/rolling-plan-ict-standardisation/cybersecurity-network-and-information-security

- Engaging in economic diplomacy with multiple partner countries and international organisations and maintaining healthy ties with third countries that supplies raw and processed materials, and/or are transit countries etc[147];
- Embarking on the Action Plan on Critical Raw Materials in September 2020, which aims to mitigate related risks. As part of this Action Plan, the European Raw Materials Alliance (ERMA) has also been established to address this threat, and monitors the progress through the annual reports on the Progress of Clean Energy Competitiveness;
- Promoting a strong and deep Single Market that is open, transparent, well-regulated and liquid, and promoting rule-based global markets to ensure a diversity of suppliers and sources;
- Adopting political guidelines for EU's energy diplomacy to enhance EU's ability to cooperate with partners in order to safeguard its values and interests of reducing strategic dependencies and increasing resilience in the area of energy, amongst others.[148]

The level of risk experienced by the EU energy supply chains per threat scenario is a function of their respective probabilities and impacts. Probability refers to the likelihood with which the threat scenario is expected to occur. The level of impact refers to the severity of the consequences experienced when vulnerabilities are exposed in the event that the threat scenario occurs. In other words, an energy supply chain may be classified as 'high risk' if there is a high possibility of it experiencing a threat, which would expose the vulnerability(s) within the supply chain, leading to severe impacts.

Each threat scenario can be broken down in a number of specific hazards. For example, extreme rainfall resulting in flooding is a hazard in the 'extreme weather events' threat. As hazards impact supply chains differently, this distinction helps to structure the analysis. Hazards impacting other EU countries can also affect the EU energy technology supply chains. For example, the 2011 Tōhoku earthquake and resulting tsunami had immediate effects in the global automotive and silicon wafer supply chain.[149]

The level of risks and impacts that could be brought about by the hazards present in the selected threat scenarios are highly uncertain, as the risks could be systemic in nature. For example, the risks and impacts on the energy supply chains could snowball and result in far-reaching impacts and disruptions to the economy. The analysis of such systemic risks is beyond the scope of this study.

In order to enhance the resilience and to safeguard the functioning of EU energy supply chains, it is necessary to first identify realistic threat scenarios which have a relevant probability of occurrence. A total of three other threat scenarios are considered in this section (in addition to COVID-19). They are namely *extreme weather events, geo-political uncertainty and tensions, and cyber threats*. The Global Risks Report 2019[150] by the World Economic Forum confirms these as key areas of concern with high impacts and likelihood. The following describes briefly individual hazards per threat scenario and their potential impact on energy technology supply chains. Further elaborations on the threat scenarios can be found in Annex D.

The rest of this section details the three other potential threat scenarios. Section 2.2.1 presents the key observations from the analysis of analysis of threat scenarios to EU energy supply chains, and section 2.2.2 presents a more detailed assessment of the potential vulnerabilities of the critical energy supply chains to the threats.

Extreme weather events

The occurrence of extreme weather events is expected to increase, as a result of anthropogenic climate change. This brings about a series of hazards which can threaten the energy sector in different ways, and to different extents. Here, we focused on the possible disruptions of the upstream

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[147] Summary of the Multi-annual Indicative Programme 2018-2020 for the Partnersehip Instrument, pg 7. Available at: https://www.gtai.de/resource/blob/32966/3c806e49c339b0dda1d8389d28ded4be/pro201806075003-data.pdf

[148] Foreign Affairs Council. (25 Jan, 2021). Council conclusions on Climate and Energy Diplomacy - Delivering on the external dimension of the European Green Deal, pg 9. Available at: https://www.consilium.europa.eu/media/48057/st05263-en21.pdf

[149] Harvard Business School. (2011). Japan Disaster Shakes Up Supply-Chain Strategies. Available at: https://hbswk.hbs.edu/item/japan-disaster-shakes-up-supply-chain-strategies

[150] The other areas of concern highlighted are economic vulnerabilities and environmental fragilities. World Economic Forum. (2019). Global Risks Report 2019, pg 9. Available at: http://www3.weforum.org/docs/WEF_Global_Risks_Report_2019.pdf

supply chain, and not on the downstream supply chain stages of operations and maintenance for example. The hazards of extreme temperature, extreme precipitation and high-intensity hurricanes are discussed in this study. The consideration of the impacts resulting from these extreme weather events is not limited to the EU boundaries, but are extended to relevant non-EU countries and regions. These three hazards can affect the energy technology supply chains in different ways. For example, extreme temperatures can affect industry productivity. Extreme precipitation and high-intensity hurricanes can affect the access of production sites to reliable supplies of raw and processed materials as well as the access of workers to these sites due to transportation disruptions, which can lead to disruptions further downstream of the supply chain stages such as manufacturing and construction and installations.

Cyber threats

Digital technologies are increasing in importance for all energy technologies. While increasing digitalisation of the energy sector is essential in the transition to a decarbonised economy, and can help improve the productivity, efficiency, reliability, and sustainability of energy systems, it also brings about new operational risks, including cyber security and data privacy risks. The EU recognises the importance of addressing cybersecurity and its related challenges, and has taken a series of measures in that regard[151]. The characteristics of the energy sector brings additional challenges to address cybersecurity. Firstly, the real-time requirements of some energy technologies pose additional challenges to implement security patches or updates as they may affect the real-time operations which could lead to undesirable consequences. In addition, the interconnectivity of electricity and gas networks across and beyond the EU could potentially increase the scale and impact of a cyber attack due to systemic effects. Lastly, the EU energy system consists in part of older legacy systems which are now combined with new technologies. These legacy systems were designed and built well before considerations to cybersecurity were made, and can expose the current energy system to vulnerabilities,[152] although gradually such systems are being replaced.

The cybersecurity issues which are related to supply chains comprises of the:

- **Integrity of digital technology components and their supply chain, i.e.**
    - i. unintentional vulnerabilities which may not be identified (or not identified in a timely manner);
    - ii. the lack of timely updates and security patches by technology suppliers;
    - iii. backdoors or hidden functions which may be embedded in digital components used in the energy sector. These functions can be employed by malicious actors (including by breaching a legitimate supplier and infecting its digitally-signed products (see Textbox 2-2 on the SolarWinds incident) to compromise (segments of) the energy sector;
    - iv. the widespread deployment of end-point digital equipment, due to the decentralization of energy systems. End-users employing these equipment may not be aware of the cybersecurity risks nor have sufficient knowledge to mitigate them;
- **Outsourcing of infrastructures and services**:
    - iv. the engagement of 3rd party service providers, such as data services and telecommunication networks, may also increase the cyber risks to the energy companies, as there may be vulnerabilities in their cyber environment, which may provide a point of entry into the systems of energy companies, and have the potential to disrupt the wider energy sector.

Textbox 2-2 SolarWinds incident

SolarWinds is a company based in Austin Texas which is a provider of IT infrastructure management software. The company also offers IT management and monitoring solutions for governments. A cyber attack on the company's Orion Platform software was discovered in December 2020, which affected some of their clients using it. The perpetrators inserted a malware known as 'SUNBURST', as part of a legitimate software update, which was code-signed. The usage of digital, code-signed certificates is an established industry-standard to help end-users authenticate and verify the source of the update, which should be checked and cleared for viruses and malicious codes by the software developer. The perpetrators of the cyber attack had managed to compromise the code-signing process, and impersonated the trusted accounts of SolarWinds, delivering malicious codes that were digitally signed. The malware inserted a backdoor function which allows attackers to access the IT system of their clients using the Orion Platform software.

[151] European Commission. (2020). Critical infrastructure and cybersecurity. Available at: https://ec.europa.eu/energy/topics/energy-security/critical-infrastructure-and-cybersecurity_en
[152] Ibid.

This cyber attack affected many high-profile clients, including Fortune 500 corporations and multiple US government agencies. The compromised systems of the US government agencies include the e-mail accounts of thousands of employees, systems used by high-ranking officials, and the systems at the National Nuclear Security Administration which contains sensitive and classified information regarding the nuclear weapons stockpile of the US. The scale of the attack is massive, requiring extensive resources to secure the compromised systems. The SolarWinds incident highlights the important of managing cyber security risks within supply chains, where a system breach in one area within the supply chain could find its way through the interconnected networks and result in widespread and devastating consequences.

Geo-political uncertainty and tension

Energy has a close relationship with geopolitics, and the topic of energy security is often viewed as an important subset of national security. The energy transition is expected to have significant impact on societies, economies and geopolitics globally, transforming existing economic and trade patterns. A rapid global shift could exacerbate competition for access to critical raw materials and technologies necessary for the energy transition, posing challenges for security of supply. Dependency on third countries for raw and processed materials, components and equipment, and the concentration of non-EU suppliers can make the EU vulnerable to geo-political uncertainty and tensions which may arise between EU and third countries, between third countries, or due to the political instability outside of the EU. In particular, the EU may be vulnerable to hazards such as disruptions to supply routes, increases in trade tariffs and the implementation of other measures, such as export restrictions imposed by major exporters of raw and processed materials, components and equipment to the EU. Trade measures adopted by the EU may also have an impact on downstream supply chain stages, even if such impacts are adequately considered when taking the decision on adopting such measures.

2.2.1. Key observations from the analysis of threat scenarios to EU energy technology supply chains

Discussions with EU industry associations indicated that many have neither considered nor assessed the impact of these threat scenarios on their supply chains, even when they are aware of and manage direct risks to their assets in their business continuity plans. Out of the three threats assessed on top of COVID, cybersecurity is most often considered by stakeholders. While increasing attention is being given to cybersecurity, more efforts are placed in protecting against direct attacks (e.g. by phishing) than addressing cyber vulnerabilities related to the supply chains. Nonetheless, attention is being increasingly paid to managing such supply chain risks of hardware and software, which can also be required by information security standards such as ISO/IEC 27001:2013, which contains a specific annex on supplier relationships.

There are remaining gaps to fill for the implementation of coordinated and integrated emergency preparedness and disaster recovery plans across the different energy technologies within the EU. In the current Council Directive 2008/114/EC, the definition of European Critical Infrastructure only includes the sector and sub-sectors of electricity, oil and gas in the energy sector. A 2017 paper published by the Protection of Critical Energy Infrastructure (PCEI) Experts Group of the European Defence Agency (EDA) indicated the need to increase policy and operational focus on the resilience and preparedness at both the Member State and EU level.[153] An evaluation of the Directive 2008/114 also highlighted its limitations and proposed revisitation of elements to better achieve its objectives—this includes consideration of additional measures to increase resilience, the inclusion of additional sectors other than energy and transport in the scope, and to take into consideration of the evolution of the nature of threats facing critical infrastructure in the EU[154]. Building the resilience of the energy sector against the three identified threat scenarios goes beyond the technical aspects of strengthening and improving existing systems and/or infrastructure, but will also require other efforts including collective governance, integrated regulations and capacity building, and other measures.

Recognising this need, a package of measures to further improve the resilience and incident response capacities of public and private entities, competent authorities and the EU as a whole in the field of cybersecurity and critical infrastructure protection has been proposed by the European Commission in December 2020. This includes a proposal for a new directive to enhance the resilience of critical entities providing essential services in the EU, which suggests the setting up of a Critical Entities

[153] European Defence Agency. (2017). Protection of critical energy infrastructure: Conceptual Paper. Available at: https://eda.europa.eu/docs/default-source/events/eden/phase-i/information-sheets/cf-sedss---protection-of-critical-energy-infrastructure-conceptual-paper.pdf

[154] European Commission. SWD(2019) 310 final. Available at: https://ec.europa.eu/home-affairs/sites/homeaffairs/files/what-we-do/policies/european-agenda-security/20190723_swd-2019-310-commission-staff-working-document_en.pdf

Resilience Group, which will facilitate regular cross-border cooperation and information exchange with regards to the implementation of the directive[155]. In addition, this new directive will also be closely aligned with, and establish close synergies with the revision of the NIS Directive (the Directive on security of network and information systems), namely the NIS 2 Directive.[156]

While the threat hazards may differ in characteristics, they may eventually result in similar impacts to the EU energy technology supply chains. For example, pandemics, extreme weather conditions and geo-political tensions can all result in a disruption of trade flows, and may as a result lead to increasing cost of imports for EU Member States. These vulnerabilities primarily stem from supplier concentration and import reliance of the EU and/or Member States on particular countries or regions. A summary of the key impacts of the four threat scenarios, and their root causes of vulnerabilities are listed in Table 2-2.

Table 2-2 Summary of key impacts of threats and their root causes

Key impacts of threats	Threats	Root cause(s) of vulnerability(s)
Disruption in trade flows, including flow of staff and contractors from non-local countries	• Persistent pandemics • Extreme weather conditions • Geopolitical tensions	• Supplier concentration • Import reliance
Restriction of access to physical worksites and production plants	• Persistent pandemics • Extreme weather conditions	• Supplier concentration • Dependence on physical presence
Longer delivery time and other logistical issues	• Persistent pandemics • Extreme weather conditions • Geopolitical tensions	• Supplier concentration • Import reliance
Disruption in the functioning of critical energy infrastructure	• Cyber threats	• Lack of robust internal cybersecurity policies and procedures • Lack of standards and regulations on cyber security
Restriction of access to online and remote systems		
Increase in cost of imports to the EU from third countries	• Persistent pandemics • Extreme weather conditions • Geopolitical tensions	• Supplier concentration • Import reliance

Supplier concentration, in both EU and non-EU countries, is a common root cause for vulnerability for the threat scenarios of (extended) pandemics, extreme weather events, and geo-political uncertainty and tension, although the level of risks differs in the various threat scenarios. As mentioned earlier in section 2.1.1, disruptions experienced from intra-EU / European suppliers were more lasting than those from non-European suppliers during the COVID-19 pandemic. Supplier concentration can also increase the risks of disruptions from extreme weather conditions. For example, extreme heat can disrupt road, rail and air freight operations, which could affect the movement of goods and materials from within the EU. Manufacturing of components for e.g. gas infrastructure is concentrated in regions such as Northern Italy, which could be significantly disrupted by an extreme weather event. Similarly, supplier concentration in third countries or regions, could also increase the risk of disruptions to the EU energy supply chains in case of extreme weather events in those countries or regions. In addition, supplier concentration in non-EU countries also puts EU energy technology supply chains at a higher risk of geo-political uncertainties and tensions. For example, China is the main exporter of rare earth metals. Geo-political tensions between the US and China have resulted in a price increase of rare earth metals such as neodymium and dysprosium, both of which are used in wind technologies.[157] In another example, palladium, a material largely exported by Russia, is used in multiple energy technology supply chains of hydrogen,

[155] European Commission. (December 16, 2020). The Commission proposes a new directive to enhance the resilience of critical entities providing essential services in the EU. Available at: https://ec.europa.eu/home-affairs/news/commission-proposes-new-directive-enhance-resilience-critical-entities-providing-essential_en
[156] European Commission. (2021). Revised Directive on Security of Network and Information Systems (NIS2). Available at: https://ec.europa.eu/digital-single-market/en/news/revised-directive-security-network-and-information-systems-nis2
[157] Reuters. (2019). Explainer: China's rare earth supplies could be vital bargaining chip in U.S. trade war. Available at: https://www.reuters.com/article/us-usa-china-rareearth-explainer-idUSKCN1T00EK

smart buildings and digital technology. Geo-political tensions between the US and Russia led to the price of palladium to soar in 2014.[158]

2.2.2. Summary of threat scenarios to EU energy technology supply chains

Following the identification of hazards that are present in each of the four threat scenarios, an analysis of the vulnerabilities specific to each of the critical energy technology supply chains was carried out through desk research and discussions with stakeholders. An overview of the vulnerabilities found in each critical energy technology supply chain is presented in Table 2-3. This includes the identification of the specific stage(s) of the supply chain, and specific elements which are vulnerable to the threats and hazards, which is based on the assessment that has been carried out in Section 1.2. In addition, the vulnerabilities of the energy technology supply chains are further differentiated into those with evidence of past occurrences, as well as those that have been assessed as potentially vulnerable.

[158] Reuters. (2014). Russian palladium supply seen slipping 2 pct in 2014-GFMS. Available at: https://www.reuters.com/article/palladium-supply-russia-idAFL5N0QZ4S220140829

Table 2-3 Mapping of the vulnerability of critical energy technology supply chains to the threat hazards

Supply chain	Stage and vulnerable element(s)	Persistent pandemics						Extreme weather events			Cyber threats					Geo-political tensions		
		Border closure with 3rd countries	Closure of intra-EU borders	Restricted access to sites	Logistical issues	Administration delays	Shortage of PPE	Extreme temperatures	Extreme precipitation	High-intensity hurricanes	Unintentional vuln.	Lack of timely security updates	Backdoors / Hidden functions	3rd party service provider vuln.	Increase in end-point equipment	Disruptions to supply routes	Trade sanctions	Restriction of exports to EU
Wind	*R&PM:* Cu, Dy, Nd									x							x	
	MFG: Electrical steel Permanent magnets	x	x															
	O&M: Control systems; service providers			x									x					
Solar PV	*R&PM:* B, Ga, In, Se, Si, Te						x											
	MFG: PV cells and modules	x		x	x	x	x						x					
	O&M: Control systems; service providers											x	x					
Nuclear fission	*R&PM:* Ce, Cr, N, Zn; Ni-Cr-Fe alloys																	
	MFG: Nuclear-grade certified suppliers		x	x	x													
	O&M: Control systems; service providers												x					
Hydrogen	*R&PM:* PGMs (Pt, Pd, Ru, Rh, Ir), REE, Ti Previously H Fuel cells/stacks		x															
Gas infrastructure	*O&M*: Control systems; service providers										x			x				
Electricity networks	*R&PM:* Bi, Mg, Si	x																

Supply chain	Stage and vulnerable element(s)	Persistent pandemics						Extreme weather events			Cyber threats					Geo-political tensions		
		Border closure with 3rd countries	Closure of intra-EU borders	Restricted access to sites	Logistical issues	Administration delays	Shortage of PPE	Extreme temperatures	Extreme precipitation	High-intensity hurricanes	Unintentional vuln.	Lack of timely security updates	Backdoors / Hidden functions	3rd party service provider vuln.	Increase in end-point equipment	Disruptions to supply routes	Trade sanctions	Restriction of exports to EU
	MFG: Electrical steel																	
	O&M: Control systems; service providers										x		x	x				
Batteries	*R&PM:* Co, Li, graphite																	
Batteries	*MFG*: Li-ion cells, cathode, anode, electrolyte, separator	x	x															
Smart buildings	*R&PM:* B, Co, Ga, Ge, In, Li, Mg, graphite, PGMS, Si, W																	
Smart buildings	*MFG:* Home energy management systems	x	x															
Smart buildings	*O&M*: Energy management systems / decentralised devices														x			
Digital technologies	*R&PM:* B, Co, Ga, In, Li, Mg, graphite, PGMS, Si, W	x																
Digital technologies	*MFG:* Electronic boards, semiconductors; Servers / data storage	x	x								*	*	*	*	*			

Legend:
Orange: Potential vulnerability to hazard based on analysis
Boxes marked with "x": Previous occurrence of vulnerability documented (globally)
* Digital technologies are naturally the focal point of cyber-attacks. The analysis thus focuses on the other technology supply chains.
The application of anti-dumping tariffs and/or other trade measures are sometimes taken in order to restore a level-playing field for businesses in the EU and beyond the EU, or for environmental protection reasons. This can lead to price increases of materials and products, that may have an impact on the cost incurred by the concerned energy technologies, especially if support schemes are absent. As such, price increases relate to business competitiveness matters and have a low risk of disrupting the supply chain. Therefore, we do not regard it as a hazard to the energy supply chains in this study.

2.2.3. Impacts of three other threats (other than pandemics) on the energy technology supply chains

The following section will discuss the impacts of three other threats discussed in this study, namely extreme weather conditions, cyber threats and geo-political uncertainty and tension. The threats of a (extended) pandemic situation has been covered earlier in Section 2.1.2.

Extreme weather conditions

The increase in the frequency and intensity of weather extreme events can amplify disruptions to the energy technologies due to supplier concentration. Although energy technology supply chains have shown resilience against the risks associated with extreme weather conditions historically, the risk of disruptions will increase for energy technologies with a high concentration of suppliers that are located in regions prone to such extreme weather events in the future and with inadequate adaptation measures in place.

Extreme weather conditions generally affect the supply chain stages of manufacturing, and operation and maintenance, where physical presence of staff is required, and transport, where equipment and infrastructure may be rendered non-operational due to e.g. high-temperatures. Extreme weather conditions can lead to life-threatening or undesirable situations and can therefore halt or limit production. However, in most situations, the disruptions were felt only briefly, and operations were able to resume fairly quickly. For example, the operations of refineries in the USA due to the flooding as a result of hurricane Harvey in 2017 were disrupted for about a week, eventually restarting with reduced capacity[159]. While the effects of most extreme weather events may only briefly affect supply chains, an increase in the frequency of extreme weather events can lead to persistent disruptions experienced in the supply chains.

Cyber threats

There has been increasing evidence of the involvement of Nation State Actors in cyber attacks on the energy utilities, oil and natural gas, and manufacturing sectors globally[160]. The number of threat actors, and their capabilities are increasing, and they are evolving their techniques to remain undetected, and to increase the success rates of cyber attacks[161]. There are increasing attacks using direct phishing and spear-phishing techniques which can provide threat actors backdoor access into systems. For example, Ukraine experienced a power outage in 2015 as a result of threat actors gaining access to the network operations through phishing techniques. In addition, there are also occurrences of attackers exploiting vulnerabilities in the supply chain of digital technologies for the energy sector and in 3rd party service providers.

The accelerated adoption of digital technologies, or Internet of Things (IoT) compounds the risk exposure of the energy technologies supply chains. As the energy sector continues to digitalise, and becomes more integrated and connected, it is urgent to develop a strengthened and cohesive approach to increase cyber resilience throughout the entire energy technology supply chains.

The increase in AI use could also work as a double-edged sword—it can bring many benefits in the energy transition, but also opens a door for adversaries to exploit the vulnerabilities of the system and increase the risk and impacts of cyber attacks[162]. EU actors are starting to employ Artificial Intelligence (AI) in the energy sector. AI offers huge opportunities for the clean energy transition.[163] For example, AI can be applied in electricity trading and smart grids to bring about greater efficiency, to effectively manage the increasing number of grid participants, and to leverage demand response to integrate a higher share of renewables. However, threat actors can also tamper with, or steal the data used by EU actors to train the AI, which can then be used to replicate the same system(s) to facilitate cyber attacks across various energy technology supply chains. The use of AI can also aid threat actors in identifying the vulnerabilities in networks, devices, and applications within energy technology supply chains at a greater speed and

[159] Reuters. (2017). Texas refineries begin restart after hit from Harvey. Available at: https://www.reuters.com/article/us-storm-harvey-energy/retail-u-s-gasoline-prices-surge-on-harvey-supply-disruptions-idUSKCN1BD0B9

[160] European Union Agency for Cybersecurity. (2020). From January 2019 to April 2020: Cyber espionage – ENISA Threat Landscape. Available at: https://www.enisa.europa.eu/publications/enisa-threat-landscape-2020-cyber-espionage/at_download/fullReport

[161] Microsoft. (2020). Microsoft report shows increasing sophistication of cyber threats. Available at: https://blogs.microsoft.com/on-the-issues/2020/09/29/microsoft-digital-defense-report-cyber-threats/

[162] European Commission. (2020). COM(2020) 65 final. White Paper on Artificial Intelligence – A European approach to excellence and trust. Available at: https://ec.europa.eu/info/sites/info/files/commission-white-paper-artificial-intelligence-feb2020_en.pdf

[163] Eurelectric. (2020). AI Insights – The Power Sector in a Post-Digital Age. Available at: https://www.eurelectric.org/media/5016/ai-insights-final-report-26112020.pdf

scale than before. Real-time monitoring of malicious activities and swift patching of vulnerabilities would be necessary for the cybersecurity. As the potential for the application of AI in the business and industrial processes of the EU energy sector continues to grow along with the clean energy transition, risk management and risk mitigations should also be put in place.

A supply chain is as strong as its weakest link. Most small-medium enterprises lack the resources to properly practice cyber hygiene, which entails regular, low impact security measures including the setting up of simple daily routines for system checks, training and/or reminders on good cyber behaviours, and to carry out occasional check-ups to make sure the online health of the enterprises is in optimum condition.[164] Due to the strong level of digital interconnectivity between businesses and operations, it is imperative for all organisations across entire supply chains to integrate good cyber hygiene practices.[165]

With the blurring lines between physical and cyber interactions, and the convergence of Information Technology (IT) and Operational Technology (OT)[166], there is currently a lack of a holistic EU framework or guideline to manage the risks of both technology types.[167] Measures typically focus on IT and not on OT, nor the interactions between them which increase as control systems become increasingly interconnected. The EU has advanced on strengthening cyber security and resilience of the electricity and gas networks. Within the Clean Energy for All Europeans package, the new Regulation (EU) 2019/941 on electricity risk preparedness, and the recast of the Electricity Regulation (EU) 2019/943, and adoption of Recommendation (2019/553) on cybersecurity in the energy sector, and sector-specific guidance, i.e. Recommendation C(2019)240 final and SWD(2019)1240 final, address cybersecurity in the energy sector. Further, the EU has also adopted the Decision (EU) 2020/1479 on establishing priority lists for the development of network codes and guidelines for electricity for the period from 2020 to 2023, and for gas in 2020. The priority lists will be established every three years for the electricity sector, and yearly for the gas sector[168]. A network code addressing the cybersecurity of cross-border electricity flows is currently under development, as part of this priority list (further information is provided in chapter 3). Funded by the EU, the SecureGas project is also underway to increase the security and resilience of the European gas network against both physical and cyber threats[169]. Separately, cybersecurity for nuclear power plants (which historically has applied more strict information security standards) is covered by the cybersecurity standards framework EN IEC 62645:2020.[170]

Due to the evolving digital landscape within the energy sector, there is a general lack of knowledge and awareness by the industry professionals, and a lack of an integrated approach on tackling cyber risks of both IT and OT. There is a lack of formalized governance and security requirements of OT. Personnel in charge of the cybersecurity may also not be equipped with the tools and knowledge to properly manage the risk.

Geo-political tension

The EU is currently still at significant risk of experiencing supply disruptions from geo-political uncertainty and tension. The EU Commission has embarked on the Action Plan on Critical Raw Materials, and established the European Raw Materials Alliance (ERMA) in September 2020 to address this, including through the development of EU-based supply. However, the extent to which the proposed measures can mitigate the risks of a shortage of these materials and scale of disruptions remains to be assessed, based on the future implementation of the envisaged actions. Starting from 2020, the Commission has started publishing a yearly Report on Progress of Clean Energy Competitiveness, which will also report on critical raw material dependencies of the various renewable energy technologies.

[164] European Union Agency for Cybersecurity. (2017). Cyber Hygiene. Available at: https://www.enisa.europa.eu/publications/cyber-hygiene
[165] https://eda.europa.eu/docs/default-source/events/eden/phase-i/information-sheets/cf-sedss---protection-of-critical-energy-infrastructure-conceptual-paper.pdf, page 25
[166] IT systems include software, hardware, and technologies that process data and other information; OT systems include software, hardware, and technologies that help monitor and control physical devices, assets and processes, including Industrial Control Systems (ICS).
[167] https://www.mckinsey.com/business-functions/risk/our-insights/the-energy-sector-threat-how-to-address-cybersecurity-vulnerabilities
[168] Commission Implementing Decision (EU) 2020/1479. Establishing priority ists for the development of network codes and guidelines for electricity for the period from 2020 to 2023 and for gas in 2020. https://eur-lex.europa.eu/eli/dec_impl/2020/1479/oj
[169] SecureGas. (n.d.). Securing the European Gas Network. Available at: https://www.securegas-project.eu/
[170] CenCenelec. (2020). EN IEC 62645:2020 protects the cybersecurity of nuclear power plants. Available at: https://www.cencenelec.eu/news/brief_news/Pages/TN-2020-045.aspx

The EU energy technology supply chains are highly dependent on some countries and regions for raw and processed materials, as well as for components and equipment. The risks are expected to increase as global demand increases, as export restrictions from producing countries could have a significant downstream impact on the energy technology supply chains in the EU. Therefore, the import dependence of the EU energy technology supply chains is not only restricted to critical raw materials, but also extends to components and equipment, which may contain critical raw materials as well. For example, solar PV modules from China, battery components from China, Japan and Korea, and permanent magnets used in wind turbines mainly from Asia.

2.2.4. Assessment of the potential vulnerabilities of the critical energy technology supply chains to selected threat scenarios

In order to better understand the likely impacts on the EU energy technology supply chains in the event of the four threat scenarios which is discussed in this study, the hazards present in each of these threat scenarios were first identified. Additionally, the actual occurrences of these threats on energy technology supply chains, regardless of whether it had occurred within or beyond the EU, were also recorded. A summary table of the potential threat hazards faced by the critical energy technology supply chain per hazard is provided in Table 2-4. This table also includes the hazards that were earlier identified in section 2.1 for the COVID-19 pandemic in order to give a comprehensive overview.

Textbox 2-3 Assessing the most significant vulnerabilities faced by EU's critical energy technology supply chains

Due to future uncertainty and the complexity of the supply chains and the threats they may face, ranking the supply chain vulnerabilities and threats/hazards in order of importance is a challenging exercise that is out of scope of the present study. Nonetheless, this textbox attempts to indicate the most relevant vulnerabilities and threats based on the assessment of chapters 1 and 2.

According to the World Health Organisation (WHO), the risk of future pandemics is certain, although the severity and scale could vary – this means that future pandemics could be much more severe than COVID-19.[171] While most energy technology supply chains have shown resilience in eventually resuming supplies following a brief period of uncertainty and disruptions, a more severe pandemic could be more challenging to overcome. Pandemics could potentially result in an **extended period of disruption in trade flows, due to border closures between Member States and between EU and non-EU countries, and/or due to the lack of availability of supplies arising from constrained limited production capacities in EU or non-EU countries.** The disruption to supplies for raw and processed materials could also lead to downstream implications such as slowing down the manufacturing activity, and delaying construction and installation schedules. Our study shows that the current COVID-19 pandemic situation has led to documented disruptions in the raw and processed materials and/or manufacturing stages in 8 out of 9 of the supply chains. The solar PV supply chain was the only one with no documented disruptions experienced during COVID-19. In addition, such disruptions to trade flows could also arise from the increase in frequency and intensity of extreme weather events that would take place within the EU and beyond.

Another threat with a high likelihood of occurrence and with high impact on energy technology supply chains is cyber threat. There is evidence of increasing numbers of threat actors and enhanced capabilities which could lead to sophisticated cyber attacks, especially in the energy sector. **As the EU energy sector moves towards the further digitalisation, and with the increasing interconnectivity between the various actors within the energy sector, this will increase the risks of cyber attacks disrupting the energy technology supply chains**.

The identified EU energy technology supply chains are currently quite dependent on imports. As the global demand for raw and critical materials are expected to increase, **trade measures such as export restrictions and manipulation of prices that may be implemented by source countries could disrupt the supply chains of energy technologies in the EU**. Such actions could significantly drive up cost and prices of the operations of these critical energy technology supply chains along the various supply chain stages. The severity of this issue is also reflected by the fact that energy security has always remained a key item in the EU foreign policy agenda. The adoption of the conclusions by the Foreign Affairs Council of the EU on Climate and Energy Diplomacy in January 2021 highlights the important role of energy diplomacy in maintaining and strengthening the energy security and resilience of the EU.

[171] World Economic Forum. (2019). Outbreak Readiness and Business Impact: Protecting Lives and Livelihoods across the Global Economy. Available at:
http://www3.weforum.org/docs/WEF%20HGHI_Outbreak_Readiness_Business_Impact.pdf

Table 2-4 Summary table of the potential threat hazards to energy technology supply chains and examples of historical occurrences

Hazard	Summary	Historical occurrences
Persistent pandemic		
Closure of borders with third countries	Extra-EU border closures and restrictions will reduce the flow of goods and skilled labour, which can cause bottlenecks and delays across the various supply chain stages. The use of air freight as a delivery option will reduce as country borders are closed. Alternatives such as shipping or rail freight are still available, but will have a delay in delivery times.	- COVID-19 (Worldwide)
Closure of intra-EU borders	Intra-EU border closures and restrictions will also reduce the flow of goods and skilled labour, which can cause bottlenecks and delays across the various supply chain stages. However, with well-established protocols and systems, essential goods can still be allowed to flow within the EU.	- COVID-19 (Worldwide)
Restricted access to work sites	The extent to which non-essential sectors can continue to operate and function in work sites where physical presence is required, is highly dependent on the local measures implemented based on the severity level of the pandemic. This could remain as a highly dynamic situation for an extended period of time.	- COVID-19 (Worldwide)
Logistical issues	Social distancing measures, coupled with the need for physical presence to handle logistics processes, including customs clearance, reduces the capacity of the logistics sector in an event of a pandemic.	- COVID-19 (Worldwide)
Public administration delays	Social distancing measures, coupled with the need for physical presence to be in the office to handle specific administrative processes, can be a bottleneck for the energy technology supply chains. A lack of digitalization of processes to allow these requests to be processed from a home network (via VPN) is the main root cause of this hazard.	- COVID-19 (Worldwide)
Shortage of PPE	The onset of the COVID-19 pandemic saw an urgent shortage of PPE globally. However, the production capacity of PPE within the EU managed to keep up with the demand and has largely stabilised. This experience serves as a consideration for future emergency preparedness.	- COVID-19 (Worldwide)
Extreme weather conditions		
Extreme temperatures	Extreme temperatures can reduce the process productivity and lead to disruptions in the supply chain. For example, extreme heat or cold can reduce productivity and ability of workers and production plants.	- Heatwaves leading to flight and railway delays (EU)[172] - Heatwave affecting grid, related infrastructure and electricity workers in 2019 (USA)[173]
Extreme precipitation	Extreme precipitation in manufacturing countries can lead to disruptions in the supply chains, as access to plants and/or production sites can be shut down or heavily restricted. This disruption can have downstream implications such as reduction in the availability of supplies for raw and processed materials, and/or price increases. Extreme precipitation can also restrict movement, as well as access to carry out operation and maintenance works which require physical presence.	- Rail freight disruptions in the winters of 2008-2010 (Europe)

[172] CNBC. (2019). Flight delays and railway fires: Scorching heatwave tests Europe's infrastructure. Available at: https://www.cnbc.com/2019/07/26/scorching-heatwave-causes-flight-and-railway-delays-in-europe.html
[173] E&E News. (2019). Heat wave slams the grid. Here's what to know. Available at: https://www.eenews.net/stories/1060771407

Hazard	Summary	Historical occurrences
High-intensity hurricanes	High-intensity hurricanes can lead to disruptions in the supply chains in similar ways as in a scenario of 'extreme precipitation', i.e. forced closure or restricted operations of plants and production sites; restriction in transportation and distribution means. In addition, they can also cause significant damages to energy infrastructure and assets, leading to reductions or complete cut-off of energy supplies (electricity, oil, gas) from certain regions.	- Hurricanes (USA) - Closure of refineries due to flooding: Hurricane Harvey 2017 (USA) - Typhoon Usagi 2013 (China) - Hurricane Maria 2018 (Puerto Rico)
Cyber threats		
Unintentional vulnerabilities	The energy sector has been subjected to cyber threats due to exploits of zero-day vulnerabilities. A zero-day vulnerability refers to a security flaw in a software that is discovered but a security patch is not yet available to fix it. Other unintentional vulnerabilities are due to human error.	- Stuxnet destroyed centrifuges at an Iranian nuclear power plant through zero-day vulnerabilities 2010 (Iran)[174] - McAfee security researchers found a vulnerability in a commonly used industrial control system which can enable threat actors to manipulate building control systems by creating a backdoor through malware[175]
Lack of timely security updates / patches	Security patches are important to address vulnerabilities of software. Besides the need for vulnerabilities to be patched timely, it is also equally important for companies and organisations to have an good patch management system to ensure that the vulnerabilities can be fixed in a safe and timely manner. The challenge for the energy sector lies in the fact that many of the systems in the energy sector are running real-time, and in some cases need to react extremely fast. Cybersecurity processes, such as message authentication, may result in unacceptable delays in the energy systems. In addition, security breaches in legacy OT hardware can also result in a lengthened response time due the lack of the ability to leverage on cloud detection to defend the cyber infrastructure, the dependency on finding a suitable time to address them, and the need to create new solutions for attacks on specific OT systems and configurations[176]. The installation of security patches would also require a testing environment before deployment to ensure a smooth operation. However, these patches could also carry risks of being tempered with by actors.	- Solar and wind utilities disrupted 2019 (USA)[177]

[174] McAfee. (n.d.). What is Stuxnet? Available at: https://www.mcafee.com/enterprise/en-us/security-awareness/ransomware/what-is-stuxnet.html
[175] Software Contract Solutions. (2019). McAfee warns of serious security flaw in building controller. Available at: https://softwarecontractsolutions.com/mcafee-warns-of-serious-security-flaw-in-building-controller/
[176] McKinsey & Company. (2020). The energy-sector threat: How to address cybersecurity vulnerabilities. Available at: https://www.mckinsey.com/business-functions/risk/our-insights/the-energy-sector-threat-how-to-address-cybersecurity-vulnerabilities
[177] Threatpost. (2019). Solar, Wind Power Utility Disrupted in Rare Cyberattack. Available at: https://threatpost.com/solar-wind-power-utility-cyber attack/149816/

Hazard	Summary	Historical occurrences
Backdoors / Hidden functions	Backdoors or hidden functions are vulnerabilities which can be exploited by actors of cyber attacks to access and control systems, although it can also be an intentional built-in function for service providers to help customers troubleshoot or resolve issues. These functions can be extremely difficult to identify.	- Crash Override malware attack on a power grid 2015 (Ukraine)[178][179] - Sunburst malware which inserted a backdoor in SolarWinds software – cyber attack on multiple US government agencies and, Fortune 500 companies 2020 (USA)[180]
Increase in end-point equipment	The use of common network protocols, and increase in end-point equipment, especially in home energy management systems present systemic risk to the use of these technologies.	- Vulnerabilities in the grid and charging infrastructure for EVs were found by researchers[181] - Increase in end-point equipment in smart buildings increases risks of exploitation for launching cyber attacks[182]

[178] WIRED. (2016). Inside the Cunning, Unprecedented Hack of Ukraine's Power Grid. Available at: https://www.wired.com/2016/03/inside-cunning-unprecedented-hack-ukraines-power-grid/
[179] WIRED. (2017). Crash Override malware is targeting power grids, but how dangerous is it? Available at: https://www.wired.co.uk/article/what-is-crash-override-malware-hackers
[180] Trend Micro. (2020). Overview of Recent Sunburst Targeted Attacks. Available at: https://www.trendmicro.com/en_us/research/20/l/overview-of-recent-sunburst-targeted-attacks.html
[181] U.S. Department of Energy Office of Scientific and Technical Information. (2019). Securing Vehicle Charging Infrastructure APR. Available at: https://www.osti.gov/servlets/purl/1572920
[182] Pan, Z., Hariri, B., Pacheco, J. (2019). Context aware intrusion detection for building automation systems. Computers & Security. 85 (2019). Pp 181-201. https://doi.org/10.1016/j.cose.2019.04.011

Hazard	Summary	Historical occurrences
3rd party service provider vulnerabilities	Energy companies rely on a multitude of suppliers to provide technology and digital services. Even though these suppliers may be reputable companies that apply at least the industry standards for cybersecurity, there could still be risks of cyber attacks which could compromise their systems. As a service provider to multiple clients, a security breech could then result in massive, widespread attacks to their clients systems. The engagement of third-party service providers therefore introduces additional risks of cyber attacks for energy technology supply chains, which could lead to downtime and unintended outages along the supply chains.	- EternalBlue exploits vulnerabilities in the Microsoft Server Message Block protocol, i.e. the cause of WannaCry ransomware attacks worldwide in 2017 (Worldwide) [183][184] - 3-week disruption due to an attack on the turbine control system due to virus infection caused by usage of a USB drive used by 3rd party supplier 2012 (USA)[185] - Sunburst – cyber attack on multiple US government agencies and, Fortune 500 companies 2020 (USA)
Geopolitical uncertainty and tension		
Disruptions to supply routes	Many of the critical raw materials required to develop new infrastructure and to support the energy transition in the EU is dependent a highly concentrated number of producing countries and regions. The current maritime routes also passes through several chokepoints such as the Panama Canal, Suez Canal and the Strait of Malacca. Any disruptions to these shipping routes could lead to significant increases in logistical costs and longer delivery times. In addition, geopolitics can also lead to disruptions in air routes which could lead to disruptions in the delivery of materials which are stored in global warehouses. The bulk of air freight passes through the airports in four regions, namely Europe, the United States, Middle-East and Asia. The concentration of air freight handling in these regions could also increase the risk and vulnerability faced by the EU technology supply chains should there be any disruptions arising from local political instability, and/or geo-political tensions of these regions with the EU.	Not identified
Trade sanctions	Trade sanctions are implemented to partially or completely cut off economic relations. Examples of such sanctions include the trade sanction imposed on Russia by the EU and the USA. These impacted large Russian energy firms which can in turn impact downstream energy technology supply chains in the EU. It could also lead to price volatility of the material supplies from Russia, such as the significant global price increase experienced for the material palladium, when the US imposed sanctions on Russia in 2018. Trade sanctions can lead to more severe impacts as compared to anti-dumping tariffs, as they not only affect trading activity between EU and the third country(s), having a broader impact on various sectors within the economy, such as banking and finance, shipping, and insurance services etc.	- EU's trade sanction against Russia 2014 - USA's trade sanction against Russia 2018

[183] Panda Security. (2020. Three decades of cybersecurity vulnerabilities. Available at: https://www.pandasecurity.com/en/mediacenter/panda-security/three-decades-vulnerabilities/

[184] T&D World. (2017). Utility Companies Among Those Impacted by Ransomware Attack. Available at: https://www.tdworld.com/smart-utility/grid-security/article/20969707/utility-companies-among-those-impacted-by-ransomware-attack

[185] POWER. (2013). DHS: USB Drives Spread Malware in Control System Environment at Two Power Plants. Available at: https://www.powermag.com/dhs-usb-drives-spread-malware-in-control-system-environment-at-two-power-plants/

Hazard	Summary	Historical occurrences
Restriction of exports / Manipulation of export prices	As the global demand for raw and critical materials are expected to increase, trade measures such as export restrictions that may be implemented by source countries could disrupt the supply chains of energy technologies in the EU. These measures may be taken for reasons related to the protection of the environment, or more likely, to encourage supply of raw materials to domestic producers of downstream semi-processed products. Such actions by one country can lead other countries to follow. This in turn, may result in a smaller pool of global supplies, which can significantly drive up the cost and prices for the energy technology supply chains.	- Application of export taxes on Chromite in India almost led South Africa to follow suit[186] - China has been using rare earth export bans amidst geo-political tensions with Japan (2010), the US (2020)[187]

* Supply chains highlighted in bold are potentially exposed to the hazards, based on our analysis.

[186] Korinek, J. and J. Kim (2010), "Export Restrictions on Strategic Raw Materials and Their Impact on Trade", OECD Trade Policy Working Papers, No. 95, OECD Publishing. doi: 10.1787/5kmh8pk441g8-en

[187] Business Insider. (2019). China has been dropping hints that it will weaponize its rare earths as a trade-war tactic. Here's why it probably won't follow through. Available at: https://www.businessinsider.nl/will-china-ban-rare-earth-exports-trade-war-2019-5?international=true&r=US

3. POSSIBLE MEASURES TO INCREASE THE RESILIENCE OF THE CRITICAL SUPPLY CHAINS

The aim of this chapter is to develop a set of potential policy measures at EU, Member State or and operator level to mitigate the risks associated with the four identified threats and to strengthen the resilience of the critical energy technology supply chains.

Section 3.1 categorises the vulnerability of components belonging to the critical supply chains against the four threats' hazards and the root causes of the vulnerabilities. It then maps these main vulnerabilities to the specific policy recommendations of this study. Section 3.2 presents in detail each policy recommendation, including the problem they address, any existing related policy measures and the policy gap addressed by the recommendation, as well as the EU added value.

3.1. Problems of vulnerable components of critical supply chains

3.1.1. Supply chains' problem identification and root causes

This section translates the threats on vulnerable components of critical supply chains into problems, through the following steps:

- Pinpoint the vulnerability of the relevant component of a critical supply chain;
- Recall the different hazards possibly affecting the supply of the component;
- Focus on the identification of the root cause(s) which should be addressed;
- Translate the root cause(s) into problem areas to better describe the problems and identify possible solutions.

The general principle to address the vulnerabilities of the components and their root causes, in order to identify the required responses, has been that by reducing the vulnerability, the measures help to mitigate the risk of disruption of the supply chain to any of the four threats identified.[188] In this frame, **persistent pandemics, extreme weather and geo-political tension** are particularly related to the dependence on non-EU suppliers and market concentration.

Moreover, a number of aspects can be highlighted for each threat:

- On **persistent pandemics,** EU energy technology supply chains have shown to be resilient to the COVID-19 crisis. There were many impacts nonetheless for all supply chains, and COVID-19 has shown that disruptions experienced upstream in the energy technology supply chains have cascading impacts on downstream stages, that intra-EU difficulties can be more important than manufacturing and logistics challenges in non-EU countries, and that many EU energy technology businesses are not only dependent on imports but also on exports[189];
- On **extreme weather conditions**, the increase in the frequency and intensity of weather extreme events can amplify disruptions due to supplier concentration. While the effects of most extreme weather events may only briefly affect supply chains, larger-scale ones may have significant impacts;
- On **cyber-attacks,** such attacks on energy utilities, oil and natural gas, and manufacturing sectors globally are increasing. The accelerated adoption of digital technologies and Internet of Things (IoT) (including the Industrial Internet of Things (IIoT)) devices compounds the risk exposure of the energy technologies supply chains. Cybersecurity is often considered, but more efforts are placed in protection against direct attacks, such as phishing attacks, than addressing cyber vulnerabilities related to the broader supply chains, such as mitigation of third-party cyber risks and/or diversification of suppliers. Cyber security measures typically focus more on risk mitigation measures for Information Technology (IT) and less on Operational Technology (OT), nor on the increasing interactions between them. However, the latter is gaining increasing attention. Currently, the EU is already taking active measures to mitigate such risks (see Textbox 3-2);
- On **geo-political tension,** the EU dependence on certain regions for the supply of materials, equipment and components increases the risk of supply chain disruptions. The EU is currently still at significant risk of experiencing supply disruptions from geo-political uncertainty and tension. Moreover, the EU is highly dependent on some countries and regions for components and equipment. The EU has taken various measures to mitigate the risks associated with this threat scenario (see chapter 2).

[188] Persistent pandemics, extreme weather cyber threats, and geo-political tension
[189] Such as wind or hydro EU actors, exporting out of EU

3.1.2. Main vulnerabilities identified in supply chains

Raw materials

Europe faces a challenge when it comes to securing raw materials in a sustainable way based on its high import reliance, increasing consumption and decreasing quality and availability of resources. The European Commission has already undertaken important work to safeguard the availability of critical raw materials (CRMs) that are crucial for Europe's economy. As part of this work the Commission has produced critical raw material lists every three years since 2011. The fourth list was published in 2020 and lists 30 CRMs[190]. Furthermore, the Commission has recently launched the European Raw Materials Alliance[191] and published the 2020 Communication on Critical Raw Materials (CRMs) containing an action plan to reduce dependencies.[192]

For the energy sector, the analysis of the raw materials across the critical energy technology supply chains found that most vulnerabilities at this stage can be attributed to a combination of **market concentration** with **dependence on non-EU suppliers** often exacerbated by limited possibilities of material substitutions for many of the raw materials. For example, Europe is dependent on China for the sourcing of 98% of its supply of rare earth elements. It supplies 98% of borate from Turkey and 71% of the platinum currently needed in Europe comes from South Africa (see also section 1.2 for further information on supply risks of raw materials for key technologies).[193] This dependency exposes the EU to potential problems of sourcing the raw materials in the event of **geo-political tensions** or other external threats such as **pandemics** and/or **extreme weather** events. As an example, recent reports (February 2021) have emerged that China is considering restriction of the exports of rare earth minerals as a consequence of tensions with the United States. This move, although being directed towards the U.S., could have important consequences for Europe.[194][195] During interviews, stakeholders representing various technologies have stressed that sourcing materials from non-EU suppliers does not constitute a vulnerability in itself, but that rather the combination of this characteristic together with a high market concentration is the most problematic aspect.

Our analysis across the supply chains found that **half of the critical raw materials from the 2020 Critical Raw Material List are also crucial for the energy sector**. Our analysis confirms that raw materials are closely linked to clean technologies, more so than with established energy technologies. Technologies such as hydrogen fuel cells (14 raw materials[196]), solar PV (18 raw materials), Li-ion batteries (14 raw materials), smart buildings (22 raw materials) and digital technologies (18 raw materials) are based on a large number of different raw material elements, many of which (but not all) are considered to be vulnerable to supply chain disruptions. In the case of other technologies like wind energy, electricity networks, nuclear fission or gas turbines fewer raw material elements are needed, but these are also subject to vulnerabilities. Finally, gas infrastructure, hydropower and pumped hydro storage and heat pumps are not subject to raw material vulnerabilities. Thus, **raw material availability constitutes a particular concern for the objective of the clean energy transition** of the system rather than for the current security of energy supply.

A few elements which are not classified as critical under the 2020 CRM List are highlighted as of concern in the literature on specific energy technologies. In the case of solar PV, a recent analysis by the JRC, shows that under different demand scenarios and predicted increase in cadmium telluride

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[190] European Commission. (2020). COM(2020) 474 final. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. Available at https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en
Note: In the 2020 CRM List Light Rare Earth Elements (LREEs) (made up of 8 elements), Heavy Rare Earth Elements (HREEs) (9 elements) and Platinum Group Metals (PGMs) (6 elements) are grouped together and thus reports 30 elements where in reality it is made up of 50 periodic table elements. We decompose the groups given that not all elements in each of these groups is relevant to the analysis.
[191] European Raw Material Alliance. (n.d.). Available at: https://erma.eu/
[192] European Commission. (2020). COM(2020) 474 final. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. Available at https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en
[193] Ibid.
[194] Bloomberg. (2021). China may ban rare-earth technology exports on security concerns. Available at: https://www.bloomberg.com/news/articles/2021-02-19/china-may-ban-rare-earth-technology-exports-on-security-concerns
[195] Trakimavičius, L. for EnergyPost.eu. (2021). EU, U.S exploring new sources of Rare Earth Minerals, should China limit exports. Available at: https://energypost.eu/eu-u-s-exploring-new-sources-of-rare-earth-minerals-should-china-limit-exports/
[196] See section 1.2& Annex B (section 5.6 for HFC)

(CdTe) and copper/indium/gallium/diselenide (CIGS) based technologies, **selenium** and **tellurium** are the two elements, in addition to elements already identified as critical under the 2020 CRM list, that could face substantial increase in demand and (between 3 and 40-fold increase in demand depending on the scenario) and increased supply risks.[197] For wind energy, a study looking at the raw metal needs and supply risks for the development of wind energy in Germany until 2050 finds that **copper** and dysprosium (the latter is already on the 2020 CRM List) are the most critical materials since they face the possibility of supply bottlenecks while being fundamental to the functionality of wind turbines. The cumulative demand for copper may require 0.2% of the current known reserves. This exceeds the expected supply of cooper for renewable energy technologies in Germany and could face strong competition from other sectors with similar raw material needs.[198] In the case of nuclear fission, **chromium**, **nickel** and **zinc** are important raw materials. However, the EU has an import reliance ratio of around or over 60% for all three elements. Moreover, for these materials the foreign supply market is highly concentrated, with again the market concentration ratio of the top four suppliers (CR4) being over 60%.

Silicon has been found to be a vulnerable raw material across six technologies (HFC, solar PV, batteries, electricity networks, smart buildings and digital technologies). Silicon metal is considered a critical raw material for the EU economy. The major uses of silicon in the EU are in the aluminium and chemical industries. Silicon metal is also extensively used for renewable energy technologies and electronic devices. The EU domestic production of silicon metal represents around 32% of the total silicon metal consumed in the EU.[199]

Magnesium was found to be vulnerable across four energy technology supply chains (HFC, electricity networks, smart buildings, digital technologies). There is no production of pure magnesium in the EU, thus the supply for the manufacturing industry relies entirely on imports from China (92%) and a few other non-EU countries (Israel, Russia, and Turkey). Magnesium is considered a critical raw material by the EU. The EU apparent consumption of magnesium represents around 15% of the total consumption worldwide. In addition to its relevance for the supply chains of energy technologies Magnesium, in the form of aluminium and magnesium alloys, is used in the transport sector, packaging, construction, pharmaceuticals, steel industry and agricultural chemical production, among others.[200]

Cobalt sourcing is of concern for four energy technology supply chains (batteries, smart buildings, digital technologies, gas turbines), it is also used in fuel cells but the analysis of this supply chain did not identify major concerns related to Cobalt (given the fact Cobalt is a substitution material for Platinum). Cobalt is a critical raw material according to the EU definition. The element is considered crucial for the implementation of the EU long-term strategy for the climate neutral economy as it is required for electric vehicle batteries and energy storage systems. Cobalt is mainly produced as a by-product from nickel and copper production. In 2018, only 7% of the element was sourced from mining operations in which cobalt was the main commodity. The Democratic Republic of the Congo (DRC) is the world's dominant producer and exporter of cobalt ores and concentrates with a share of 97% of global exports in terms of value in 2017. In contrast, the EU consumption of refined cobalt mainly originates from domestic production in Finland (54% of EU sourcing) and Belgium (7% of EU sourcing).[201]

Platinum and Iridium were found to be required and subject to vulnerabilities for the supply chain of four technologies (HFC, smart buildings, digital technologies, gas turbines). In addition, other elements of the **Platinum Group Metals (PGMs)** are subject to similar concerns in the case of hydrogen fuel cells, smart buildings and digital technologies. EU mine production makes a small contribution to European platinum supply. The EU import reliance for platinum in unwrought or in powder form is 94%, excluding consumption of refined platinum metal originating from secondary materials which is produced domestically (but the EU is dependent on imports of platinum waste and scrap). Its use in autocatalysts dominates demand for platinum. In 2018, consumption of platinum in autocatalysts accounted for 39% of global demand and 75% of European demand. All PGMs are part of the 2020 CRM List.

Frequently used raw materials in the energy sector are: **copper** (7 supply chains), **nickel** (6) and **aluminium** (6), however, with the exceptions already mentioned above (nickel for nuclear fission,

[197] JRC. (2020). Raw materials demand for wind and solar PV technologies in the transition towards a decarbonized energy system.
[198] Shammugam, S. et al. (2019). Raw metal needs and supply risks for the development of wind energy in Germany until 2050.
[199] European Commission. (2020). Study on the EU's list of Critical Raw Materials (2020). Available at: https://ec.europa.eu/docsroom/documents/42883/attachments/1/translations/en/renditions/native
[200] Ibid.
[201] Ibid.

copper for wind energy), these are generally not subject to supply concerns for the energy supply chains analysed. In contrast to nickel and copper, aluminium is considered a critical raw material for the European economy, however in the case of the energy sectors no concerns were identified. Aluminium can be substituted by materials such as magnesium, titanium and steel in mobility applications or copper for certain electrical applications.[202] This, could be one of the reasons why for the energy sector this element is not currently of concern.

In general, it is concluded that the overall **assessment of critical raw materials at economy-wide level takes appropriately into account the vulnerabilities and concerns of the European energy sector** and that the findings of this study are in line with the work conducted by the Joint Research Centre on the critical raw materials for the EU economy. However, this will be further explored under the monitoring measure, addressed under section 3.4.1.

To conclude, the root causes arising from the vulnerability at the raw material stage of the supply chains mainly concerns **market concentration and dependence on non-EU suppliers**. Specific problems for the raw material stage concern the lack of EU-based primary material production; the remaining gaps in knowledge acquisition and monitoring, including at a more global scale; the gaps in addressing the vulnerable components in appropriate trade agreements; and the limited volumes of recycled materials.

Manufacturing of wind supply chain elements

Given that wind turbine manufacturers' permanent magnets are dependent on critical raw materials (neodymium and dysprosium), by extension their production is subject to certain vulnerabilities (research of material substitutes is ongoing). For manufacturing permanent magnets, the EU is fully reliant on non-EU suppliers which are heavily concentrated in a few countries with China being the dominant supplier in both cases, neodymium and dysprosium. Difficulties to enter the market for new suppliers and the lack of suitable substitutes, in particular for neodymium, result in a high overall risk of these dependencies.
A study on the raw material needs and supply risks for the development of wind energy in Germany until 2050 identifies dysprosium and **copper** as the most critical materials. Copper and dysprosium are substitutes; generators without permanent magnets (which contain Dy) contain in exchange more copper windings.

Manufacturing of PV supply chain elements

From 2008 onwards, Europe has lost considerable market share in PV cell and module manufacturing, mainly to China, which has developed into a dominant PV player. While there are some equipment manufacturers in Europe, and especially Germany, that still supply machinery and equipment to produce highly efficient solar cells and modules, the **production of cells and modules has almost entirely migrated to Asia**. EU manufacturers are net exporters of inverters. Companies such as SMA, Fronius, FIMER/ABB, Ingeteam and Power Electronics all manufacture inverters in the EU. Furthermore, the EU PV industry continue to maintain a strong presence in equipment manufacturing with companies such as Meyer Burger, Centrotherm and Schmid having a strong base in Europe. Considering that the EU has only minimal solar cell production, it is important that the EU reduces its dependency on PV cells and modules. The manufacturing capacity of solar cells appears to be the weakest link of the solar PV value chain in the EU.

Manufacturing & O&M of nuclear fission supply chain elements

The availability of nuclear-grade certified suppliers for the provision of components and structures as well as O&M services for the nuclear fission sector is considered a supply chain vulnerability.

In 2018, the EU-27 had a **trade surplus in nuclear reactors, but a trade deficit for reactor parts**, importing around 51% of its apparent demand from China, the US, Japan and Russia. For very large modern nuclear reactors (Gen III+) **forging of the pressure vessel** becomes an important supply chain bottleneck, as it requires large forging presses which are scarce worldwide and which can handle only a few vessels per year (together with orders from other economic sectors). Specifically, heavy forging capacity in operation is concentrated in Japan, China, France, and Russia. Europe lists 8 heavy forging presses overall in 6 different Member States (see fiche). No indication was found that the available EU forging capacity is not sufficient to meet forecasted demand. Furthermore, new capacity is being built in Japan and China.

With the reduced construction rate for nuclear energy plants in various regions and in Europe especially, challenges arise related to capability, i.e. the sufficient availability of qualified personnel to design, build, operate and dismantle the plants, including in the products and services supply

[202] Ibid.

chain. The sourcing of products and services is important not only for new reactor build, but also for the maintenance or upgrade of units.[203] European operators of nuclear facilities are facing challenges due to the obsolescence of 'structures, systems and components' (SSCs) and to the **difficulties in finding certified suppliers** for these SSCs when they need to satisfy higher quality standards. It is difficult in the EU to find suppliers willing to keep quality assurance program when there is not certainty on future demand.[204] The availability of certified suppliers is worsened by the use of different standards and quality management systems in various countries and regions, which limits the possibility for international sourcing of component and leads to additional certification costs. Furthermore, technical barriers to exports limit the capacity for sourcing components internationally.[205]

The limited availability of certified suppliers is therefore an important vulnerability of the nuclear supply chain. There are a number of studies which assess the problem and recommend policy responses to address it, of which commercial-grade dedication is an important one. For this reason, section 3.2 does not provide recommendations specific to the nuclear supply chain as the measures recommended in other studies are deemed sufficient, and commercial-grade dedication is further detailed in Textbox 3-1.

Textbox 3-1 Commercial-grade dedication policy response for the nuclear industry

Commercial-grade dedication (CGD) is the acceptance process providing reasonable assurance that a component or equipment produced according to non-nuclear industry standards (a commercial item) performs its intended safety function when used for safety-classified SSCs in nuclear facilities.

In European countries with a US-based nuclear regulation (where the practice originated), like Slovenia and Spain, CGD is accepted by the regulator and common practice. CGD allows NPP operators to procure components and equipment for safety-classified SSCs from suppliers that are not familiar with nuclear requirements and thus increases their pool of potential suppliers. The CGD process is performed by the NPP operator or a competent third-party organisation that acts on behalf of the NPP operator. Thus with CGD the efforts for providing reasonable assurance that the component or equipment in scope performs its intended safety function is essentially shifted from the supplier (who is not familiar with nuclear requirements) to the NPP operator or competent third party organisation.

Several organisations and recent studies support CGD as one of the solutions to address supply bottlenecks in the EU nuclear industry. The EU nuclear industry association FORATOM dedicates a specific study to the matter.[206] The JRC study "Current challenges of the European nuclear supply chain" supports commercial-grade dedication as one of the solutions (along with safety-related SSCs produced according to alternative nuclear codes and standards to that of a certain country).[207] Both studies support the development of a EU-level approach or guideline for commercial-grade dedication.

Manufacturing of batteries supply chain elements

Asia, and more specifically **China, dominates the entire Li-ion battery supply chain**. In addition to the Asian players, the USA has considerable manufacturing capabilities of Li-ion cells (13% global share). Europe currently lacks the capacity to process materials required to produce Li-ion batteries, such as anode materials and NCA cathode materials.

Although still lacking manufacturing capabilities, Europe is catching up with Asia in terms of investments in the battery sector. In fact, Europe invested significantly more than China in the sector in 2019 (60 billion EUR vs 17 billion EUR). In 2020, Europe has invested 25 billion EUR, corresponding to double the investments by China. In July of 2020, the European Investment Bank issues a 30 million EUR loan for the construction of the first domestic battery gigafactory. The factory will be constructed in Sweden by Northvolt and plans for an initial annual production capacity of 16 GWh. This capacity could eventually be ramped up to 40 GWh per year.

[203] World Nuclear Association. (2020). Launch of the World Nuclear Supply Chain: Outlook 2040 report.
[204] JRC in World Nuclear Association. (2020). Launch of the World Nuclear Supply Chain: Outlook 2040 report.
[205] International Framework for Nuclear Energy Cooperation. (2017). Global Supply Chain and Localization, Issues and Opportunities: A Conference on the Customer Dialogue – Summary Conference Report.
[206] FORATOM. (2020). Optimising the European Nuclear Supply Chain - Use of High-quality Industrial Grade Items in European Nuclear Installations.
[207] Based on: JRC. (2020). Current challenges of the European nuclear supply chain; and FORATOM (2020) Optimising the European Nuclear Supply Chain.

Manufacturing of electricity networks & wind supply chain elements (electrical steel)

The production of electrical steel used in electricity networks and the wind energy supply chains are identified as a vulnerability. Transformer manufacturing employs **domain-refined high-permeability grain-oriented electrical steel (GOES).** This premium type of GOES reduces electrical losses, allowing to reduce transformer size, which can be very important in certain applications (such as in the nacelles of wind turbines), as well as increasing energy efficiency and reducing resource use.

In 2014 there were four GOES manufacturers in the EU - ThyssenKrupp Electrical Steel, Orb Electrical Steels (UK), ArcelorMittal Frydek Mistek, and Stalprodukt - and eight outside of the EU - NLMK (RU), Nippon Steel (JP), JFE (JP), AK Steel (US), ATI (US), Baosteel (CN), Wisco (CN), Anshan (CN), Posco (KR), and ArcelorMittal Inox (BR).[208] Orb Electrical Steels, then owned by Tata Steel, closed in 2020.[209]

In 2015 the European Commission imposed anti-dumping tariffs on grain-oriented electrical steel from China, Japan, South Korea, Russia and the US.[210] The investigation supporting the anti-dumping measures adopted found that **EU supply is insufficient to satisfy the EU demand for high-permeability GOES**. In 2020 the Commission started an Expiry Review on the anti-dumping measures. The summary of the Expiry Review request[211] indicates 'GOES is a necessary component for the production of transformer cores and is therefore **crucial for the maintenance and expansion of the Union's electrical grid**. The secure functioning and expansion of the Union's electrical grid cannot be contingent upon the supply of GOES from foreign companies [. . .] The European Union must have a secure and stable domestic supply of GOES'. Hence, the summary acknowledges the strategic importance of GOES to the EU electric industry.

Manufacturing of electricity and gas infrastructure supply chain elements (control systems / 3rd party service providers)

The analysis of the electricity networks and gas infrastructure supply chain indicates a vulnerability related to the cyber-security of control systems and 3rd party service providers. This due to the real-time requirements which pose additional challenges to implement security patches or updates, the interconnectivity of electricity and gas networks across and beyond the EU, and the combination of legacy systems with new ones.[212] These legacy systems were designed and built well before considerations related to cybersecurity gained prominence, and can expose the current energy system to vulnerabilities,[213] although gradually such systems are gradually being replaced.

Electricity and gas control systems could be compromised through ITC service providers or vulnerabilities in IT and OT equipment. Actions to address this risk are being taken not only in the EU but also for example in the US.[214] The 2020 SolarWinds incident highlighted the extent that cyber-attacks originating through service providers can take (see textbox 2-2 in chapter 2). Cyber- and overall electricity system security is not only relevant to the EU but to European countries in general (and even Morocco, Algeria and Tunisia) which are part of the continental European synchronous area.

Manufacturing and O&M of smart buildings supply chain elements

The analysis of the smart buildings supply chain indicates that there are vulnerabilities concerning the operation of energy management systems and decentralised devices and home energy management software.

Energy management systems and decentralised devices may be vulnerable to cyber-attacks, where common protocols and increase in end-point equipment, especially in home energy management systems, lead to the systemic risk of thousand/millions of devices being affected. This risk can be

[208] Impact Assessment accompanying the Draft Commission Regulation implementing Directive 2009/125/EC with regard to small, medium and large power transformers. SWD(2014) 162
[209] Tata Steel. (2019). Tata Steel Europe announces outcome of sales process for non-core businesses.
[210] Commission Implementing Regulation (EU) 2015/1953 imposing a definitive anti-dumping duty on imports of certain grain-oriented flat-rolled products of silicon-electrical steel originating in the People's Republic of China, Japan, the Republic of Korea, the Russian Federation and the United States of America.
[211] Executive Summary of the expiry review request concerning imports of grain-oriented flat-rolled products of silicon-electrical steel ("GOES") originating in the People's Republic of China, Japan, the Republic of Korea, the Russian Federation and the United States of America. Available at: https://trade.ec.europa.eu/tdi/case_details.cfm?id=2492&publication=3200&action=readfile
[212] European Parliamentary Research Service. (2019). Briefing - Cybersecurity of critical energy infrastructure.
[213] European Commission. (2020). Critical infrastructure and cybersecurity. Available at: https://ec.europa.eu/energy/topics/energy-security/critical-infrastructure-and-cybersecurity_en
[214] Public-Private Analytic Exchange Program. (2017). Supply Chain Risks of SCADA/Industrial Control Systems in the Electricity Sector: Recognizing Risks and Recommended Mitigation Actions.

heightened by the need for technology vendors to improve processes for monitoring, identifying, notifying and patching (un)intentional vulnerabilities that allow cyberattacks due to supply chain-related vulnerabilities. Vulnerabilities to building automation and control systems could arise from the use of open source and free network programs and code and embedded functionalities[215], i.e. a functionality that is built-in the equipment but not activated (such as Wi-Fi or TCP/IP connectivity), which can be activated (possibly remotely) and be used to gain access to the device. As for cyber-security aspects of electricity networks and natural gas infrastructure, given the number of studies and policy measures to increase the cyber-security of the energy sector (see Textbox 3-2), no specific recommendations on cyber-security of smart buildings are presented in section 3.2.

The EU is a leader in building automation and control systems. Lead suppliers include Siemens Building Technologies (DE), Honeywell Technologies (US), Johnson Controls (US), Schneider Electric Buildings (FR), accounting for around 54% of the EU market.[216] ABB (CH), GE and Eaton (US) also provide BEMS.[217] For building energy management software specifically, the EU is also a leader. Others comprise EcoEnergy Insights (US), Acuity Brands (US) and ThoughtWire (CA).[218]

Potential vulnerabilities in home energy management (HEM) software arise because while EU companies are frequently leaders in the market for building automation and control systems, the US is leader in home energy management software. Lead US-based HEM software vendors include Bidgely, Itron, Oracle and Uplight. Only Schneider Electric (FR) is listed as a main supplier based in Europe. Siemens does offer HEM solutions, but is not listed as a leading player in HEM software by the Clean Energy Transition – Technologies and Innovations report. Delta-E does list over 50 companies with some level of involvement with the HEM market across Europe in 2020.[219] There is, therefore, a large number of new entrants in the market – also globally. Hence, the vulnerability is mitigated by the fast growth of the sector, which counts with several new entrants, including European ones – which means that eventually EU companies may assume a stronger global leadership in the development of home energy management software, also considering they are already leaders in many other parts of the industry for smart buildings and related products. The EU HEM software market is much smaller than the BEM software one, amounting to under 250 million EUR in 2020, against over 2 billion EUR for the latter. [220]

Additionally, by relying heavily on digital technologies, the smart buildings supply chain use of a number of raw materials is also a vulnerability, but this is addressed in the broader analysis of the digital technologies for the energy sector supply chain (see next section).

Manufacturing of digital technologies supply chain elements

The analysis of the digital technologies supply chain indicates electronic boards, semiconductors and processors as well as servers and data storage equipment as vulnerable elements.

The EU has a significant participation in the global production of digital components such as embedded electronics, sensor systems or power electronics (e.g. 23% for embedded electronics), but produces only 10% of the world's electronic boards and 9% of its semiconductors and microprocessors.[221][222]

The Asia Pacific region is responsible for over 60% of the global semiconductor production. Taiwan, South Korea, Japan and the US are leaders in wafer production, and South Korea and US companies are leaders in semiconductors production – with China coming in 5th place and having a strategy to develop capabilities in all stages of the electronics value chain, including semiconductor production. The main EU suppliers of electronic boards in 2018 were China, Thailand, Taiwan and Hong Kong, with 82% of exports to the EU then. This highlights that the EU is dependent on external, non-EU suppliers for semiconductors and electronics boards. These are an essential element for all electronic equipment, be it stand-alone or embedded. The EU has nonetheless many strengths in the electronics sector, including in equipment manufacturing, power and industrial electronics, being e.g. a leader in the programmable logic controllers (PLC) market.

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[215] Brooks et al. (2017). Building automation & control systems – an investigation into vulnerabilities, current practice & security management best practice.
[216] VITO et al. (2020). Ecodesign preparatory study for Building Automation and Control Systems (BACS) implementing the Ecodesign Working Plan 2016 -2019 - Draft final Task 2 report: Markets
[217] E-LAND. (2019). D7.1 Market and stakeholder analysis. Available at: https://elandh2020.eu/wp-content/uploads/2020/09/D7.1-Market-and-stakeholder-analysis.pdf
[218] Guidehouse. (2020). Insights Leaderboard: Intelligent Building Software.
[219] Delta-EE. (2020). Accelerating the energy transition with Home Energy Management.
[220] European Commission. (2020). Clean Energy Transition – Technologies and Innovations. SWD(2020) 953.
[221] European Commission. (2020). Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study.
[222] European Political Strategy Centre. (2019). Rethinking Strategic Autonomy in the Digital Age.

The EU is also largely dependent on non-EU suppliers for servers and data storage equipment, with the main manufacturers being HPE (Hewlett Packard, US), Dell (US), Lenovo (China), IBM (US), Cisco (US) and Fujitsu (Japan, with also manufacturing based in Germany). The EU digital technologies supply chain has an external dependence not only on a number of components and equipment, but also on critical raw materials – this is, however, addressed in the raw materials section above.

Therefore, the main causes of vulnerability for the EU digital technologies supply chains are the external dependence on EU trade partners and the concentration of suppliers in a handful of countries for electronics boards (CN, TW, TH and HK) and semiconductors (TW, KR, JP, US) especially. Given these causes of vulnerability, several threats could disrupt the EU supply chain:

- COVID-19 has already demonstrated that persistent pandemics could affect the electronics sector in the EU, although disruptions where short-lived thanks to the relatively quick restoration of manufacturing and logistics activities in Asian countries. Nonetheless, future persistent pandemics could lead to a longer disruption of manufacturing and logistics in main EU trade partners for digital technologies, affecting the EU supply chain;
- Geo-political tensions with the major supplying countries – China, Japan, South Korea, Taiwan or the US - could also cause significant disruptions in case of e.g. export restrictions;
- Extreme weather events could also have disruptive effects in case it affected a particularly important manufacturing region for electronic boards or semiconductors, although this would be highly dependent of the scale of the event, as short-lived disruptions would likely have minimal impacts to the EU supply chain.

3.1.3. Summary of problems for each supply chain

Table 3-1 summarises the main problems that may occur to the vulnerable elements identified in each supply chain, according to the logic presented above.

Table 3-1 Problems arising from SCs vulnerabilities

Supply chain, critical element and stage	Threats	Description	Root cause	Related recommendation (see Table 3-2)
Several Supply chains (SCs)	All threats	- There are knowledge gaps regarding vulnerabilities of strategic energy technology supply chains for the various stages, from raw material sourcing to manufacturing and O&M.	- Gaps in risk monitoring	- 1. Set up an integrated monitoring and reporting of vulnerabilities for critical energy technologies and supply chains - 2: leverage diplomacy and trade measures
			- EU companies not fully aware of vulnerabilities and threats / lack risk mitigation and emergency measures	- 5. Improve risk assessment and management by relevant entities
Several Supply chains (SCs) – multiple critical raw materials	Extreme weather (High-intensity hurricanes) Geo-political tensions	- Restriction of exports to EU due to trade measures by EU partners or extreme weather in mining/processing regions could significantly disrupt supply of materials / dependent components, especially for CRMs with very high concentration.	- Dependence on non-EU suppliers, with: o Supplier concentration o Gaps in trade o Lack of EU based primary material production o Limited recycling of critical materials o Lack of material substitution R&I	- 2: leverage diplomacy and trade measures - 3. Develop EU-based production of raw and processed materials - 7. Integrate circular economy measures (recycling & substitution)
Solar PV – PV cells and modules (manufacturing)	Geo-political tensions Extreme weather Covid-19	- External dependence (mostly from CN, TW, KR, US) for cells and modules leading to supply disruptions due to export restrictions by EU partners / extreme weather or pandemics disrupting production in critical regions for prolonged periods of time	- Dependence on non-EU suppliers, with: o Limited EU-based manufacturing o Supplier concentration o Gaps in trade agreements	- 2: leverage diplomacy and trade measures - 4. Leverage EU alliances to address supply chain risks
Nuclear fission - Nuclear-grade certified suppliers (manufacturing, O&M)	Geo-political tensions	- Nuclear-grade structures, systems and component suppliers already face difficulties due to high certification costs, increasing dependence on Asian suppliers. Geo-political tensions could restrict access to these products and services.	- Dependencies on non-EU suppliers - Lack of EU guidelines for commercial-grade products use	- See textbox 3-1
Batteries – Li-ion cells, cathode, anode, electrolyte, separator (manufacturing)	Geo-political tensions Extreme weather Covid-19	- EU is practically fully dependent on CN, JP and KR for all major components, although initiatives are in place for developing domestic capacities. Any of the threats indicated could significantly limit supply.	- Dependence on non-EU suppliers, with: o Limited EU-based manufacturing o Supplier concentration o Gaps in trade agreements	- 2: leverage diplomacy and trade measures - 4. Leverage EU alliances to address supply chain risks
Electricity networks/wind – electrical steel (manufacturing)	Geo-political tensions	- The transformer ecodesign regulation requirements increase demand for high-quality electrical steel, while development of domestic production capacity lacks even with anti-dumping measures in place.	- Dependence on non-EU suppliers, with: o Lack of EU-based manufacturing o Supplier concentration	- 4. Leverage EU alliances to address supply chain risks - 6. Continue the analysis of supply chain vulnerable elements in preparatory studies for ecodesign product-specific regulations
Electricity and gas infrastructure - control systems / 3rd party service providers (O&M)	Cyber security	- Need for improved processes for technology vendors monitoring, identifying, notifying and patching (un)intentional vulnerabilities can allow cyberattacks due to SC-related vulnerabilities - Service providers can be entry points for cyber attacks.	- Lack of/incomplete cybersecurity policies and procedures; - Lack of/incomplete third-party and vendor risk management	- See textbox 3-2

Supply chain, critical element and stage	Threats	Description	Root cause	Related recommendation (see Table 3-2)
Smart buildings – energy management systems and decentralised devices (O&M)		- Common protocols and increase in end-point equipment, especially in home energy management systems, increase systemic risk of thousand/millions of devices being affected.	- Use of common hardware/ software/ protocols for decentralised/IoT devices combined with their use on large scale - Need for increased cooperation through multi-lateral fora and international organisations	- See textbox 3-2
Smart buildings – home energy management software (manufacturing)	Geo-political tensions	- While EU companies are frequently leaders in the market for building automation and control systems, the US is leader in home energy management software (although the sector does count with several new entrants, including European ones)	- Supplier concentration - Leadership of US suppliers, although field is developing rapidly	- 2: leverage diplomacy and trade measures - 4. Leverage EU alliances to address supply chain risks
Digital technologies – electronic boards, semiconductors and processors (manufacturing)	Geo-political tensions Extreme weather Covid-19	- The EU produces only around 10% electronic boards, semiconductors and processors, although it has leadership in e.g. industrial electronics and equipment for electronics manufacturing. Any of the threats indicated could significantly limit supply.	- Dependence on non-EU suppliers, with: o Limited EU-based manufacturing, especially for large wafers	- 2: leverage diplomacy and trade measures - 4. Leverage EU alliances to address supply chain risks
Digital technologies – servers and data storage equipment (manufacturing)	Geo-political tensions Extreme weather Covid-19	- EU is highly dependent on Asian and North American suppliers for servers and data storage, albeit it has some companies and manufacturing capacity. Any of the threats indicated could significantly limit supply.	- Dependence on non-EU suppliers, with: o Limited EU-based manufacturing o Gaps in trade agreements	- 2: leverage diplomacy and trade measures - 4. Leverage EU alliances to address supply chain risks

3.2. Recommendations to increase the resilience of critical supply chains

Based on the analysis conducted in chapters 1 and 2, we conclude that the vulnerabilities to external events such as pandemics, extreme weather, and geo-political tension stem most frequently from two major root causes: dependence on non-EU suppliers in combination with high market concentration. To address these in order to increase the energy supply chains resilience, a common logic can be followed:

1. Encourage **substitution, whenever possible,** of the critical elements used in EU energy technologies supply chains. This involves a coordinated R&I effort by EU companies, academia and policy makers and can provide results only in the medium- to long-term;

Then, when dependency on the critical elements cannot be reduced:

2. **Diversify primary supply** (intra-EU and from third countries) and develop **back-up supply sources** for raw materials as well as manufactured components**,** this being a pivotal element given the EU external dependence on critical elements cannot be fully reduced or only in the long-term. Attention should be given to ensure that the EU sources materials and components from responsible sources, with adequate environmental and human rights protection;
3. **Develop secondary supply of critical raw materials** as far as possible**,** i.e. recycling, in order to further reduce the external dependence on these critical raw materials, in coordination with other circular economy measures;
4. Develop **EU supply capacities** considering available resources, economic feasibility and social and environmental impacts. While the development of EU mining, processing and recycling of raw materials or manufacturing of critical components should be feasible to various extents, fully eliminating the EU dependence on non-EU sources would likely not be feasible or advantageous given economic, social and environmental considerations;
5. **Mitigate** the risk of disruption of the chains that cannot be diversified, through cooperation with non-EU governments and critical suppliers;
6. Finally, **ensure continuity of supplies and manufacturing** in case of emergencies, through cooperation and other applicable measures where possible, such as emergency stocks.

Cybersecurity vulnerabilities are of a different nature, and therefore require a specific approach:

7. Fostering voluntary / mandatory requirements for businesses conducting supply chain management processes to ensure the integrity of their supply chain for Information Technology (IT) and Operational Technology (OT) systems, products and services.

The specific problems identified for each critical supply chain in the previous section can be grouped into a number of main problem areas. This allows to identify problems which are common to multiple supply chains and to develop horizontal measures addressing vulnerabilities in multiple supply chains, if applicable. These horizontal measures can complement supply chain-specific measures which are better tailored to address problems which are not encountered in other critical supply chains. It must be noted that the implementation of horizontal measures may still require supply chain-specific actions. This section details each policy recommendation corresponding to the main problem areas mapped in Table 3-2. Annex E comprises the broader list of potential policy responses considered and the rationale for selecting or excluding these, based on arguments such as the existence of critical supply chain problems to be addressed, whether any existing or proposed policy instruments already adequately address the problems, and the EU added value.

Table 3-2 Main problem areas and correspondent policy recommendations

Main problem area with underlying root causes	Correspondent policy recommendation
1. There are knowledge gaps regarding vulnerabilities of strategic energy technology supply chains	• **Recommendation 1:** Set up an integrated system for monitoring and reporting of vulnerabilities for critical energy technologies and supply chains • **Recommendation 2:** Leverage diplomacy and trade measures
2. There is a high external dependence for a number of <u>critical raw materials</u> from specific supplier countries, with high supplier concentration and limited EU-based primary production for a number of materials, and gaps in trade framework	• **Recommendation 2:** Leverage diplomacy and trade measures • **Recommendation 3** Develop EU-based production of raw and processed materials

Main problem area with underlying root causes	Correspondent policy recommendation
3. There is a high external dependence for a number of vulnerable components for critical supply chains, with limited EU-based manufacturing, high supplier concentration, and gaps in trade framework	• **Recommendation 2:** Leverage diplomacy and trade measures • **Recommendation 4:** Leverage EU alliances to address supply chain risks
4. EU companies in critical energy technology supply chains are not fully aware of vulnerabilities and threats nor have developed mitigation and emergency measures	• **Recommendation 5:** Improve risk assessment and management by relevant entities
5. Product-specific ecodesign regulations can impact the external dependence on vulnerable components (positively or negatively)	• **Recommendation 6:** Continue the analysis of supply chain vulnerable elements in preparatory studies for ecodesign product-specific regulations
6. There is a need to develop circular economy measures such as recycling, material substitution and other efficiency measures	• **Recommendation 7:** Further integrate circular economy measures (recycling & substitution)

There is a number of studies as well as existing or proposed policies for increasing the cyber-security of entities in the EU energy sector, including by the consideration of vulnerabilities arising from the supply chain and 3rd party service providers. The most relevant policy instruments are briefly presented in Textbox 1-1. The impacts especially of the future electricity network code and the NIS 2 Directive on increasing the resilience of energy supply chains against cyber threats will still need to be evaluated. For this reason, the recommendations of this chapter do not address cyber security specifically, although it is identified as a main aspect in Table 3-1. Recommendation 5 does cover the NIS 2 Directive in the context of ensuring supply chain-related risks are assessed and mitigated by essential / critical entities in the EU energy sector.

Textbox 3-2 Cyber-security policy responses

In 2019, the Commission published a recommendation on cybersecurity in the energy sector,[223] recommending several measures on the topic. The 2019 Regulation on Risk-preparedness in the Electricity Sector[224] requires the ENTSO-E to submit to ACER a methodology for identifying regional electricity crisis scenarios, including cyber threats, and also contains measures for the consideration of cyber threats in national plans. Moreover, the process for developing a cybersecurity network code for cross-border electricity flows has started.[225] In April 2021, ACER launched the public consultation on the Framework Guidelines which will serve to guide ENTSO-E in the process of developing the network code.[226] The Draft Framework Guidelines details aspects such as the process of cross-border risk assessment and requirements for supply **chain** security and cybersecurity certification of components.[227] Also, the Regulation on Security of Gas Supply[228] requires Member States to prepare preventive action plans and emergency plans. The first Directive on the Security of Networks and Information Systems (NIS Directive) contains several measures to enhance cyber security, such as requiring the development of national strategies on security of network and information systems, fostering cooperation, and requiring Member States to assure risk management by 'operators of essential services', which includes many entities in the energy sector. The proposed **revised Directive on Security of Network and Information Systems (NIS 2 Directive)** expands the scope of the NIS Directive, and adds

[223] European Commission. (2019). Commission Recommendation on cybersecurity in the energy sector C(2019) 2400 final. Available at: https://ec.europa.eu/energy/sites/ener/files/swd2019_1240_final.pdf
[224] Regulation (EU) 2019/941 on risk-preparedness in the electricity sector
[225] ACER. (February 24, 2021). ACER and energy regulators will draft new Framework Guidelines on sector-specific cybersecurity rules for cross-border electricity flows.
[226] ACER. (2021). Public Consultation on the Draft Framework Guideline on sector-specific rules for cybersecurity aspects of cross-border electricity flows. Available at: https://www.acer.europa.eu/Official_documents/Public_consultations/Pages/PC_2021_E_04.aspx
[227] ACER. (2021). Framework Guideline on sector-specific rules for cybersecurity aspects of cross-border electricity flows (Draft). Available at: https://documents.acer.europa.eu/Official_documents/Public_consultations/PC_2021_E_04/Draft%20Framework%20Guideline%20on%20sector-specific%20rules%20for%20cybersecurity%20aspects%20of%20cross-border%20electricity%20flows.pdf
[228] Regulation (EU) 2017/1938 Concerning Measures to Safeguard the Security of Gas Supply

new elements – including specific attention to supply chain-related cyber security aspects. The **standard ISO/IEC 27001 on information security** already addresses supplier relationships but although common is of a voluntary nature - the NIS 2 Directive would add stronger cyber security requirements regarding the supply chain.

Textbox 3-3 Experience from energy security of supply measures to increase the resilience of supply chains

There is a large experience in the energy sector regarding measures to guarantee the security of energy supply, for oil products, electricity and gas. While these measures apply to energy commodities, they could in some cases, with adaptations, serve to increase the resilience of energy technology supply chains. The main lessons learned which can be drawn for security of energy supply measures regard:

- Stress tests (i.e. supply source or route disruption simulation) and reliability criteria (such as N-1 or stochastic criteria): for both materials and components of critical supply chains, risk assessment measures such as simulating disruptions due to the loss of the largest supplier can be useful. Reliability criteria where e.g. the loss of the largest supplier for an element of a critical supply chain should not lead to a supply capacity below a certain threshold or a price increase above a certain percentage could serve as a guide to identify important vulnerabilities and implement adequate measures. The Residual Supply Index is an established criteria to indicate the reliance on a large supplier and could be applied for a number of supply chain elements for which market data exists, including materials but also manufactured components. Nonetheless, conducting such a simulation for the impact of the loss of e.g. the largest supplier of electrical steel can be difficult due to the lack of appropriate data or a sufficiently robust model to estimate the economic impacts with the level of detail of a specific supply chain. In those cases, employing an indicator to assess supply chain vulnerabilities such as the concentration ratio of the largest 3 or 4 suppliers can already help estimate the impact of potential disruptions;
- Demand-side management: Long-run demand-side management measures such as material substitution and R&I in new technologies can contribute to reduce the dependency on materials as well as components with a concentrated supply. Short-run demand-side management measures (such as activation of flexible demand) are more difficult to apply to energy technology supply chains, as reducing material or component consumption cannot be done without reducing technology supply (unless emergency stockpiles are available, as indicated below) and alternative materials and components are difficult to employ on short notice;
- Strategic reserves: strategy reserves or emergency stockpiles are established mechanisms to increase the security of supply of oil products, electricity and gas. They could be applied particularly for critical raw materials for which a dependency on a single supplier exists or where a liquid and transparent global market exists. Several design aspects need to be considered: 1) they can be managed by governments or industry (voluntarily or due to regulatory requirements); 2) reserves may be used for commercial purposes or may be kept separate; and 3) companies may need to maintain their own reserves or purchase 'certificates' from others. Strategic reserves for vulnerable manufactured components are much more difficult to implement appropriately, as they are not a homogeneous product (i.e. not a commodity) and product obsolescence would quickly render the reserve outdated.

Therefore, security of energy supply measures are very well suited to increase the resilience for the supply of critical raw materials, as both energy products and raw materials are homogeneous products. They can also be applied for manufactured components, although issues related to cost effectiveness and component obsolescence become more important. Nonetheless, assessment measures such as stress tests, reliability criteria and demand-side management can be applied to both materials and components supply to a larger extent. This can be done by companies (as part of the measures covered in recommendation 5), or by/in cooperation with governments.

3.2.1. **Recommendation 1:** Set up an integrated system for monitoring and reporting of vulnerabilities for critical energy technologies and supply chains

Problem area description

This recommendation addresses the problem that there are **knowledge gaps for EU and national decision makers, and for industries regarding vulnerabilities of strategic energy**

technology supply chains. Monitoring already exists for some vulnerable components, but may be required for specific technologies, components, materials or even skills.

Knowledge and intelligence are preconditions for identifying vulnerabilities of critical energy technology supply chains and implementing risk mitigation measures. Appropriate monitoring is required to understand the market trends, identify the risks due to high concentration, anticipate possible disruptions, and assess the impacts of new developments (e.g. the impact of climate policies and the deployment of certain technologies, which may strongly affect the whole supply chains, from the extraction of raw materials to dismantling).

In their conclusions of 25 March 2021[229], the **Members of the European Council** "*invite the Commission to identify further systems of critical technologies and strategic sectors, in order to strengthen and refine the European policy approach towards them*", which highlights the importance to identify critical systems, in order to improve their resilience.

Given the fact some technologies and solutions are only at an infancy level of development, and may sharply become of high importance and have a dominant weight in global markets in the coming years/decades (e.g. PGMs for hydrogen are a very small market, but a rapid deployment of FCH may impact the whole PGMs market), close monitoring will be required. Therefore, clear dashboards and regular updates are essential. This monitoring should identify and characterise all vulnerable elements of all critical energy supply chains.

Existing policy instruments

In September 2020, the Commission announced actions to make Europe's Raw Materials supply more secure and sustainable.[230] In this frame, the Commission launched its **Action Plan on Critical Raw Materials**[231], and published the fourth **List of Critical Raw Materials**[232] updated in 2020 reflecting the changed economic importance and supply challenges based on their industrial application. It also published the **foresight study on critical raw materials**[233] for strategic technologies and sectors from the 2030 and 2050 perspectives.

The Commission developed the **Raw Materials Information System (RMIS[234])** and will reinforce it. To this end, the Commission will strengthen its work with **Strategic Foresight Networks**[235] to develop robust evidence and scenario planning on raw materials supply, demand and use for strategic sectors.

The **Raw Materials' profiles**[236], as developed in the RMIS, covers, for a selection of raw materials: key facts and figures, resources and reserves, supply and demand, raw material supply chain, market, R&D, and environmental and social sustainability aspects. These profiles provide detailed information for each raw material, allowing to highlight risks, in order to anticipate any type of threats to disrupt the concerned supply chain.

E.g., the platinum profile (belonging to the PGM group), provides specific information regarding:

- Data on global supply show a possible risk of supply associated with water stress risk in the main global supplier (South Africa). It is important to note that the extraction and processing of platinum group metals is very water demanding. Special attention should be given to extreme weather events threats;

[229] Statement of the Members of the European Council. (2021). Available at: https://www.consilium.europa.eu/media/48976/250321-vtc-euco-statement-en.pdf

[230] European Commission. (September 3, 2020). Commission announces actions to make Europe's raw materials supply more secure and sustainable. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1542

[231] European Commission. (2020). Critical Raw Materials Resilience: Charting a Path towards greater Security and sustainability. Available at: https://ec.europa.eu/docsroom/documents/42849

[232] European Commission. (2020). Study on the EU's list of Critical Raw Materials (2020). Available at: https://op.europa.eu/en/publication-detail/-/publication/ff34ea21-ee55-11ea-991b-01aa75ed71a1/language-en

[233] European Commission. (2020). Critical materials for strategic technologies and sectors in the EU – a foresight study. Available at: https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

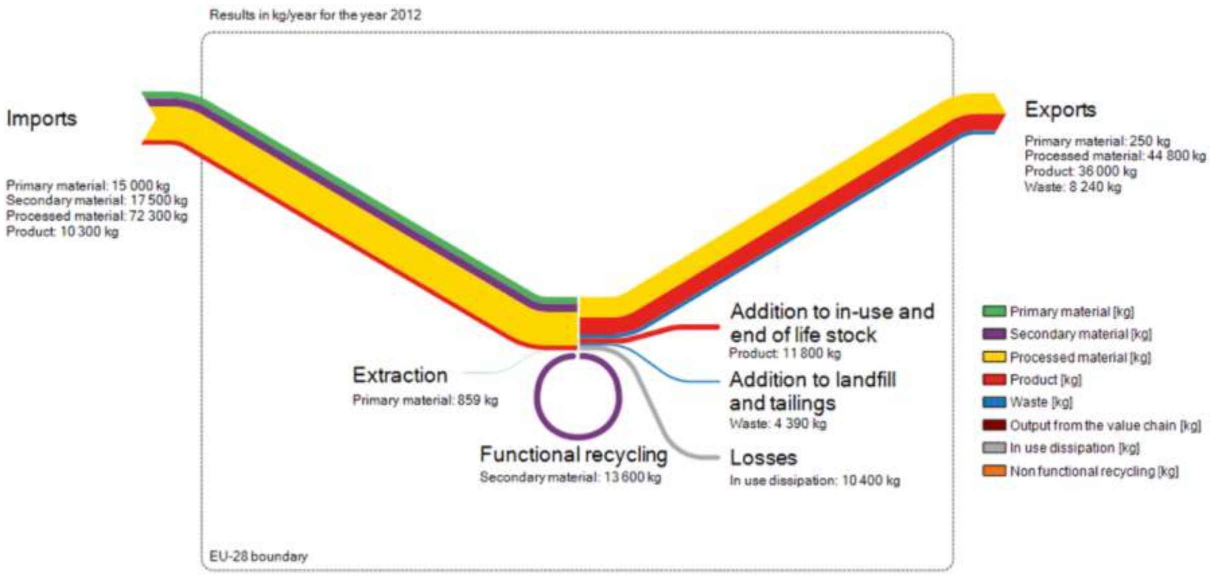
[234] European Commission. (2021). Raw Materials Information System (RMIS). Available at: https://rmis.jrc.ec.europa.eu/

[235] European Commission. (n.d.). Strategic foresight. Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/new-push-european-democracy/strategic-foresight_en#:~:text=Related%20links-,What%20is%20strategic%20foresight,systemic%20way%20to%20anticipate%20developments

[236] European Commission. (2021). Raw Materials Information System (RMIS) - Platinum. Available at: https://rmis.jrc.ec.europa.eu/?page=rm-profiles#/Platinum

- PGM are highly recyclable due to their noble characteristics and durability in use, as well as because very high recovery rates of the metal content can be achieved once the PGM-containing scrap reaches a refinery. Therefore, the potential for effective recycling is generally excellent. The main barrier to recycling of PGM lies in ensuring that end-of-life products are collected and enter an appropriate recycling chain. The recycling rate of end-of-life products varies considerably by country and application. The profiles also shows that only a limited share of the platinum flows in EU are recycled in the EU economy (as illustrated by Figure 3-1).

Figure 3-1 Simplified Sankey diagram of platinum flows through the EU economy for 2012[237]



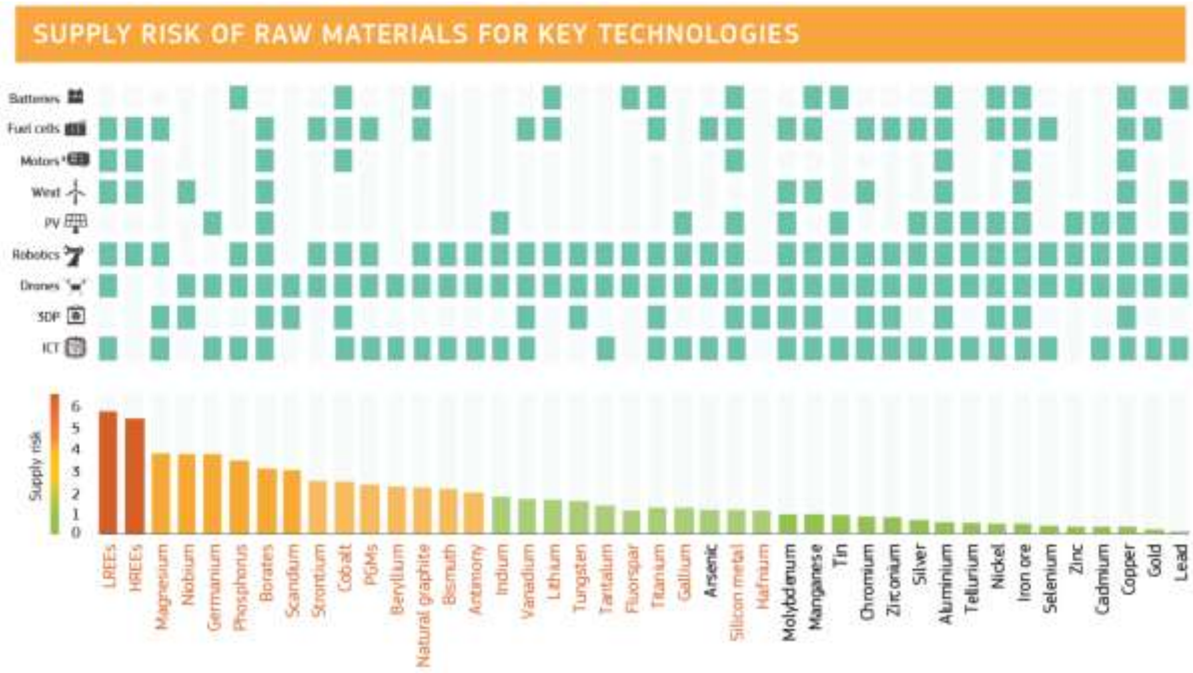
Source: Bio by Deloitte (2015)

The JRC foresight study supports the translation of the climate-neutrality scenarios for 2030 and 2050 into the estimated demand for raw materials. The report provides a systematic analysis of supply chain dependencies for nine selected technologies used in three strategic sectors, including renewable energy and e-mobility.

For example, the report indicates that for batteries in EVs and stationary storage, the EU economy would require up to 18 times more lithium and 5 times more cobalt in 2030 than today (and almost 60 & 15 times more respectively in 2050). Demand for rare earths used in permanent magnets, e.g. for electric vehicles, robots or wind generators, could increase tenfold. Figures for hydrogen and fuel cells deployment still need to be assessed regarding the reliable supply of platinum group metals. The following table illustrates the raw materials used in key technologies for the digital and green transitions, and their relative supply risk.

[237] Source from European Commission. (2020). Raw Materials Information System (RMIS) – CRM list 2020. Available at: https://rmis.jrc.ec.europa.eu/?page=crm-list-2020-e294f6

Figure 3-2 Supply risk of raw materials for key technologies[238]



These tools help identify which raw materials, both from primary and secondary sources, that are the most critical and require continued research and innovation policies for substitution. Their deep assessment and understanding could also lead to more sustainable product design.

The **List of Critical Raw Materials**[239] provides the global view on all critical material. The communication on "**Critical Raw Material Resilience: Charting a Path towards greater Security and Sustainability**" (COM(2020) 474[240]) highlights related priorities and recommends key areas of work for the EU to reinforce its strategic approach towards more resilient raw materials value chains, as presented in Textbox 3-4. To that end, the Commission will work in close partnership with other EU institutions, the European Investment Bank, Member States, regions, the industry and other key stakeholders. It will monitor progress in implementing the strategic priorities and actions, explore any additional support measures needed and make relevant recommendations by 2022 at the latest.

A first annual **report on progress of clean energy competitiveness**[241] aims to assess the state of the clean energy technologies and the EU clean energy industry's competitiveness to see if their development is on track to deliver the green transition and the EU's long-term climate goals. This is based on the identified technology needs for achieving the 2030 and 2050 targets on the basis of the impact assessment referred to in the European Commission's Climate Target Plan scenarios. It is focusing on investments in wind energy, solar electricity, storage (batteries), using electricity in transport and industry, producing renewable hydrogen, deploying smart grid technologies. An in-depth analysis, including that of additional clean and low-carbon energy technologies, is included in the staff working document '**Clean Energy Transition – Technologies and Innovations Report**' (CET TIR) that accompanies the report on competitiveness.[242]

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[238] Ibid.
[239] European Commission. (2020). Study on the EU's list of Critical Raw Materials (2020). Available at: https://op.europa.eu/en/publication-detail/-/publication/ff34ea21-ee55-11ea-991b-01aa75ed71a1/language-en
[240] European Commission. (2020). Critical Raw Materials Resilience: Charting a Path towards greater Security and sustainability. Available at: https://ec.europa.eu/docsroom/documents/42849
[241] European Commission. (2020). Report from the Commission to the European Parliament and the Council on progress of clean energy competitiveness. COM(2020) 953 final. Available at: https://ec.europa.eu/transparency/regdoc/rep/1/2020/EN/COM-2020-953-F1-EN-MAIN-PART-1.PDF in accordance with the requirements of Article 35 (m) of Regulation (EU) 2018/1999 (Governance Regulation)
[242] SWD(2020)953 – This includes buildings (incl. heating and cooling); CCS; citizens and communities engagement; geothermal; high voltage direct current and power electronics; hydropower; industrial heat recovery; nuclear; onshore wind; renewable fuels; smart cities and communities; smart grids – digital infrastructure; solar thermal power.

Textbox 3-4 Critical Raw Material Resilience: charting a Path towards greater Security and Sustainability – list of actions

Action 1 – Launch an industry-driven European Raw Materials Alliance in Q3 2020, initially to build resilience and open strategic autonomy for the rare earths and magnets value chain, before extending to other raw material areas (industry, Commission, investors, European Investment Bank, stakeholders, Member States, regions).
Action 2 – Develop sustainable financing criteria for the mining, extractive and processing sectors in Delegated Acts on Taxonomy by end 2021 (Platform on Sustainable Finance, Commission).
Action 3 - Launch critical raw materials research and innovation in 2021 on waste processing, advanced materials and substitution, using Horizon Europe, the European Regional Development Fund and national R&I programmes (Commission, Member States, regions, R&I Community).
Action 4 - Map the potential supply of secondary critical raw materials from EU stocks and wastes and identify viable recovery projects by 2022 (Commission, EIT Raw Materials).
Action 5 - Identify mining and processing projects and investment needs and related financing opportunities for critical raw materials in the EU that can be operational by 2025, with priority for coal-mining regions (Commission, Member States, regions, stakeholders).
Action 6 – Develop expertise and skills in mining, extraction and processing technologies, as part of a balanced transition strategy in regions in transition from 2022 onwards (Commission, industry, trade unions, Member States and regions).
Action 7 - Deploy Earth-observation programmes and remote sensing for resource exploration, operations and post-closure environmental management (Commission, industry).
Action 8 – Develop Horizon Europe R&I projects on processes for exploitation and processing of critical raw materials to reduce environmental impacts starting in 2021 (Commission, R&I community).

Although focusing on Critical Raw Materials, these actions are related to the recommendations of this study.

Finally, this study could also be complemented by other recent works regarding the resilience of the energy system for the global progress towards a low carbon economy. The **IEA World Energy Outlook special report on "The Role of Critical Minerals in Clean Energy Transitions"** (IEA, May 2021[243]) provides a more global perspective and identifies global challenges for the sustainable and secure supply of critical minerals and metals for the global energy transition. According to the report, high geographical concentration, long lead times to bring new mineral production on stream, declining resource quality in some areas, and various environmental and social impacts all raise concerns around reliable and sustainable supplies of minerals to support the energy transition. This again raises the importance of a comprehensive and global integrated system for monitoring and reporting of vulnerabilities for critical supply chains.

Policy gap

Not all critical raw materials are already covered under the **Raw Materials' Profiles** section in the RMIS. At the moment only the following materials out those identified as critical for the energy sector, within the frame of this study (see chapter 2) are: boron, chromium, cobalt, lithium, graphite, and the PGM family of elements. In addition, if the information is already available for some materials, these data require some update. The **JRC Foresight Study** on Critical Raw Materials for Strategic

[243] IEA. (2021). The role of Critical Minerals in Clean Energy Transitions – Part of World Energy Outlook. Available at: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

Technologies and Sectors in the EU[244] covers the following supply chains: batteries, fuel cells, wind, motors, PV and ICT (which could be considered closely linked to smart buildings and digital technologies supply chains). The following chains and components, deemed critical in this report, are not included in the report: hydrogen electrolysers, nuclear fission, electricity networks, gas infrastructure. Other strategic chains such as hydropower, heat pumps and gas turbines are also not considered.

The **report on progress of clean energy competitiveness** and the '**Clean Energy Transition – Technologies and Innovations Report**' (CET TIR[245]) accompanying report are including onshore and offshore wind energy, solar photovoltaics, renewable hydrogen through electrolysis, batteries, buildings (incl. heating and cooling), high voltage direct current, nuclear energy, smart grids - digital infrastructures. The following chains and components, deemed critical in this report, are not analysed: gas infrastructure and gas turbines.

There is currently no gap identified in the **list of CRMs**. However several raw materials that are not considered in the list of CRMs are deemed vulnerable and may require specific monitoring, such as aluminium (for hydropower, batteries, heat pumps), chromium (for nuclear fission), copper (for wind, PV), nickel (for nuclear fission, batteries), selenium (for PV), tellurium (for PV), zinc (for wind, nuclear fission). The reason for this could be due to differences in methodologies and thresholds to determine criticality between the two studies. The JRC assessment is based on two main criteria: the economic importance and the supply risk. Economic importance considers the share of the end use of a given raw material in one sector in comparison to the share of the sector in total value added.[246] It is possible that, given that some of the renewable technologies are still emerging, their economic impact presently is not large enough. Furthermore, the demand for many of these raw materials (e.g. aluminum, copper, zinc) is forecasted to grow substantially in the timeframe up to 2030 and 2050 as renewable energy technologies become more dominant.

Textbox 3-5 Forecast of demand for materials

To exhaustively assess the risks on the supply of critical materials, the global forecast of the entire market demand should be factored in, beyond the supply for the energy system. This would require an important work of coordination to assess the trend of all markets, to identify where the main increase could come from. There is no specific literature nor data on global demand forecast of critical materials. For a given material, the impact on the energy system would depend on the share of the concerned supply chain demand to the global demand (e.g. Cobalt demand will be strongly impacted by the deployment of batteries, while even an important increase in electrolysers would have a limited impact on the global demand of Titanium).

For a supply chain (e.g. electricity networks), to estimate the demand for critical materials (e.g. grain oriented steel), there is need to forecast the deployment of the chain (e.g. would the transition drastically increase the amount of electricity network installed km?). Such estimation, for the energy supply chains with a limited share of a material global demand (e.g. electricity networks are far from dominating the overall demand for grain oriented steel), would be of limited interest and would require lots of efforts. Basing the forecast on historical trends whenever relevant could be an appropriate approach.

For non-critical materials, such as aluminium or copper, this could also become an issue if global demand increases.

Necessity and EU added value to act

The EU and the world are moving towards a more sustainable energy system. Addressing concerns about greenhouse gas emissions, local air pollution, cost-competitiveness, and security of energy supply are among the main reasons for this global shift. As a consequence, the demand for a number of supply chain components will strongly increase, at EU and probably at global scale. This will also increase the pressure on different materials and components, beyond the current markets.
For all these products, individual national market sizes would most of the time be too small compared to global markets, therefore a compiled EU market approach would ensure an appropriate market

[244] European Commission. (2020). Critical materials for strategic technologies and sectors in the EU – a foresight study. Available at: https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

[245] European Commission. (2020). SWD(2020)953. Clean Energy Transition – Technologies and Innovations. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0953

[246] JRC. (2021). Raw Materials Information System, The European Commission's Critical Raw Materials Dashboard. Available at: https://rmis.jrc.ec.europa.eu/?page=crm-dashboard-e90826

size, for an effective monitoring. Sourcing databases (EUROSTAT) or studies (e.g. JRC) are EU-based initiatives which are deemed the most relevant for regular update. For trade and diplomatic reasons, monitoring and all ensuing measures would be more efficiently coordinated at EU, than at Member State level.

However, for certain reasons, such as a high share of EU industrial activity, some Member States may choose to start their own monitoring, which should ideally be coordinated with the EU systems, to ensure compliance.

Objective and description of recommended policy measure

Given that knowledge and intelligence are preconditions to design adequate policy measures, the objective would be here to:

- ensure all vulnerable components of the critical energy supply chains are appropriately considered in the scope of monitoring systems;
- ensure the operation and update[247] of the databases and monitoring systems (including reports) are able to capture the rapid changes in the use of materials and components that may increase the risk of disruption (e.g. demand of cobalt for batteries is increasing so fast in China that the country decides to curb the export), or on the contrary that may decrease the risks related to high concentration in non-EU regions (e.g. carbon fibres for hydrogen tank storage are produced by EU manufacturing);
- ensure the identification of RD&I needs to support the development of RD&I agendas (at EU and national level).

<u>Recommendation 1.1: </u>Set up a mechanism for integrated monitoring and reporting of vulnerabilities for critical energy technologies and supply chains to:

- ensure it builds on the existing reports and sources of information (see recommendations 1.2 to 1.5) and does not create additional administrative burden, but provide a useful central way to follow up all threats to the critical energy supply chains. This could be a kind of central dashboard managed by DG ENER;
- <u>address all concerned CRM, processed materials, and other components of the critical technologies.</u>

<u>Recommendation 1.2</u>: address the missing critical raw materials in the RMIS material profiles and update regularly, especially those with an expected strong increase in consumption due the EU or even worldwide uptake of strategic energy technologies. For some materials, data are from 2012, for others 2017. The more frequently the data are updated, the more rapidly measures can be taken to react to important market changes. The frequency of updates should be determined as a balance between administrative burden and risk magnitude (e.g. material of fast deploying technologies, such as cobalt for batteries, should be updated more regularly than magnesium for electricity network). RMIS is a JRC system[248];

<u>Recommendation 1.3</u>: Expand the scope of the **JRC Foresight Study** on Critical Raw Materials for strategic technologies and sectors in the EU considering the following chains components: hydrogen electrolysers (even if most of the components are similar to fuel cells, some materials like carbon fibres or titanium could be added); electricity networks (with a focus on electrical steel & control systems), gas infrastructure (with a focus on control systems), hydropower & heat pumps. In addition to those supply chains considered in the long-term climate transition, additional supply chains deemed critical in the frame of this study could also be addressed, such as nuclear fission (with a focus on high grade structures and suppliers). Gas turbines' raw materials are already covered, via the other technologies.

<u>Recommendation 1.4</u>: continue the identification and monitoring of vulnerable elements for critical supply chains for the transition towards 2050 in the work of the Low Carbon Energy Observatory[249], via the next annual reports, and possibly add gas infrastructure and turbines, which are not yet addressed in the Competitiveness Progress Report and the associated '**Clean Energy Transition – Technologies and Innovations Report**' (CET TIR[250]).

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[247] The frequency of the updates should depend on the level of risk, directly linked to the importance of a material for a rapidly growing market (e.g. raw materials for batteries or fuel cells would face important changes while materials for already existing technologies would be less impacted). The higher the impact, the more frequent updates.

[248] This means the updates should be carried out by JRC. Updates upon request (e.g. by DG ENER) may be an option to explore.

[249] European Commission. (2021). Low carbon energy technologies: successes and opportunities. Available at: https://ec.europa.eu/jrc/en/news/low-carbon-energy-technologies-successes-and-opportunities

[250] European Commission. (2020). SWD(2020)953. Clean Energy Transition – Technologies and Innovations. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0953

The above identified vulnerable components of the critical energy supply chains and the regular update of the monitoring systems should support:

- aligning or mainstreaming the RD&I agendas;
- guiding energy diplomacy actions and trade measures (addressed under recommendations 2 and 3);
- preparing the agenda of alliances or even the creation of new alliances (addressed under recommendations 4);
- adding CER and NIS 2 Directive proposals requirements for MSs to assess risks regarding respective cybersecurity and critical entities (addressed under recommendation 5);
- developing circular economy measures (addressed under recommendation 7).

Recommendation 1.5: mainstream energy technologies to be tackled in the various actions set in the communication on "**Critical Raw Material Resilience: Charting a Path towards greater Security and Sustainability**" (COM(2020) 474[251]).

Impact of recommended policy measure

The prioritised inclusion of critical raw materials in the RMIS material profiles would help Member States, regulators and companies, especially manufacturers, concerned by the critical energy supply chains, to take appropriate mitigation measures[252] based on up-to-date information. A regular or even automatic update would reinforce this, particularly for the emerging markets, such as batteries & EVs, FCH, smart building and digital technologies. This would apply to all types of hazards.

The recommended measure could lead to additional administrative costs to complete the database of the RMIS raw materials profiles, including the automatic link to the underlying data management systems. It could therefore have a slight administrative negative effect.

The recommended measure would have a slight positive impact on EU competitiveness, unless the concerned companies and industries are not taking advantage of the different monitoring systems. Globally, the recommended measure would have a positive cost-benefit ratio given the benefits to increase supply chain resilience, and potentially additional competitiveness of EU companies and the low additional administrative costs.

[251] European Commission. (2020). Critical Raw Materials Resilience: Charting a Path towards greater Security and sustainability. Available at: https://ec.europa.eu/docsroom/documents/42849

[252] The measures are those concerned by recommendations 2 to 6.

Table 3-3 Summary table for recommendation 1

Summary – 1. Set up an integrated system for monitoring and reporting of vulnerabilities for critical energy technologies and supply chains	
Measure description	
Description	The objective of this measure is to set up an integrated system for monitoring and reporting of vulnerabilities for critical energy technologies and supply chains based on the following recommendations: Recommendation 1.1: Set up a mechanism for integrated monitoring and reporting of vulnerabilities for critical energy technologies and supply chains. Recommendation 1.2: address the missing critical raw materials in the RMIS material profiles and update regularly, especially those with an expected strong increase in consumption due the EU or even worldwide uptake of strategic energy technologies. Recommendation 1.3: Expand the scope of the JRC Foresight Study on Critical Raw Materials for strategic technologies and sectors in the EU. Recommendation 1.4: continue the identification and monitoring of vulnerable elements for critical supply chains for the transition towards 2050 in the work of the Low Carbon Energy Observatory, via the next annual reports, and possibly add gas infrastructure and turbines, which are not yet addressed in the Competitiveness Progress Report. Recommendation 1.5: mainstream energy technologies to be tackled in the various actions set in the communication on "Critical Raw Material Resilience: Charting a Path towards greater Security and Sustainability" (COM(2020) 474).
Timeline of implementation	Medium term (within next policy cycle, 2-3 years)
Implementation responsibility	EU level
Nature of policy action	Continuing the implementation of current policy instruments / Improving existing policy instruments
Existing policy instruments affected	• RMIS (Raw Material Information system) • Foresight study[253] • Clean Energy Transition – Technologies and Innovations Report' (CET TIR[254]
Elements of critical supply chains affected	• Rare earths (SC: wind, digital technologies) • PGMs (hydrogen and fuel cells, smart buildings, digital technologies & gas turbines) • Aluminium, Boron, Bismuth, Chromium, Cobalt, copper, Gallium, Germanium, Indium, Lithium, Magnesium, Natural Graphite, Nickel, Selenium, Silicon, Titanium, Tungsten, Zinc
Vulnerabilities	• **Suppliers concentration** is one of the most important vulnerabilities, occurring for the critical raw materials listed under table below
Related threats and hazards	• **Persistent pandemics** can affect the production sites, and their ability to continue producing the expected amounts (when demand is increasing) • **Extreme weather events** can affect mining and extraction (e.g. PGM requiring water may be affected in the case of droughts) • **Geo-political tensions** can lead to disruption of supply chains (also caused by an increased use of the same raw material, for possibly the same purpose)
Assessment of the proposed measure	
Impact on the resilience of critical supply chains	• Should increase the knowledge and intelligence on all critical components in a centralised way; • Should support the identification of risks on these components (ideally via an easy-to-read dashboard), given the development of the various technologies; • Should support the identification of areas requiring additional RD&I efforts
Impact on EU competitivenes s	• Indirectly positive, as monitoring supports identify ways to strengthen & diversify, therefore increase the competitiveness;
Cost-benefit ratio	• Positive given benefits to resilience of EU critical energy supply chains and low associated costs (administrative costs to strengthen the tools, and adapt their update)

[253] European Commission. (2020). Critical materials for strategic technologies and sectors in the EU – a foresight study. Available at: https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

[254] European Commission. (2020). SWD(2020)953. Clean Energy Transition – Technologies and Innovations. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0953

Summary – 1. Set up an integrated system for monitoring and reporting of vulnerabilities for critical energy technologies and supply chains	
Best practices	
Best practices	• RMIS raw materials' profiles[255], like Cobalt, Chromium, PGMs,… • The foresight study on critical raw materials[256] covering Wind, PV, batteries, motors & ICT • The report on progress of clean energy competitiveness[257] covering wind energy, solar electricity, storage (batteries) and EVs, electricity in industry, hydrogen production and smart grid technologies

*3.2.2. **Recommendation 2**: Leverage diplomacy and trade measures*

Problem description

The convergence of almost all problem areas (monitoring knowledge gaps, high external dependence for some elements with high supplier concentration, limited EU-based primary materials production, limited EU-based manufacturing, gaps in trade framework, EU companies lacking knowledge of vulnerabilities and systemic risks) leads to the need for addressing them in the overall framework of diplomacy and trade measures. Diplomacy provides the overarching political framework, and also opens the door to specific European external relationship and actions. Building coalitions, increasing diplomatic outreach, adapting or even strengthening trade agreements are all means which can increase the resilience of critical energy supply chains.

In its conclusions of 25 January 2021 on Climate and Energy Diplomacy - Delivering on the external dimension of the European Green Deal[258], the European Council recalls that:

"

> *9/ EU energy diplomacy will aim – as its primary goal – to accelerate the global energy transition, while ensuring affordability, safeguarding the environment and achieving the Sustainable Development Goals.*
>
> *12/ EU energy diplomacy has a key role in maintaining and strengthening the energy security and resilience of the EU and our partners. The Council recognises that the nature of energy security is evolving from concerns about access to fossil fuels at affordable prices sourced on volatile markets, towards the need to secure access to the critical raw materials and technologies necessary for the energy transition whilst avoiding new dependencies, as well as ensuring resilient supply chains, cybersecurity and the protection and climate adaptation of all, and in particular, 'critical' infrastructure. On the way towards a climate neutral world, EU energy diplomacy will pursue energy security and resilience by promoting open, transparent, well-regulated, liquid, and rule-based global markets ensuring a diversity of suppliers and sources, and promoting the use of the Euro in energy trading."*

These statements of the European Council highlight the importance of increasing the resilience of the EU economy during the transition to climate neutrality, while encompassing the sustainability dimension, including environmental and societal concerns (incl. human rights, child protection, all related SDGs), on EU territory and in all trade relationships.

Last but not least, even if some of the present study's recommendations intend to decrease the external dependency of EU economy on the supply of critical elements, such as deploying EU-based mining (recommendation 3) and manufacturing (recommendation 4), accelerating RD&I efforts for substitution, or recycling of materials (recommendation 7), external trade will remain an important pillar to tackle in order to increase the resilience of the energy system.

Existing policy measures

Energy diplomacy plays a key role in maintaining and strengthening energy security and resilience of the EU, also through anticipating and managing geopolitical risks. The need to secure access to the critical raw materials and technologies necessary for the energy transition, as well as ensuring

[255] European Commission. (2021). RMIS portfolio. Available at: https://rmis.jrc.ec.europa.eu/?page=crm-dashboard-e90826

[256] European Commission. (2020). Critical materials for strategic technologies and sectors in the EU – a foresight study. Available at: https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

[257] European Commission. (2020). SWD(2020)953. Clean Energy Transition – Technologies and Innovations. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0953

[258] European Commission. (2021). Council conclusions on Climate and Energy Diplomacy - Delivering on the external dimension of the European Green Deal. Available at: https://www.consilium.europa.eu/media/48057/st05263-en21.pdf

resilient supply chains, will need to be further mainstreamed in EU diplomacy and dialogues with specific partners. The EU will enhance its ability to work with partners by developing a comprehensive and coordinated approach to coalition-building and diplomatic outreach including through the network of EU delegations.

The EU's **common commercial policy** (CCP), or trade policy, has evolved gradually over the years to encompass a range of trade-related areas under the exclusive remit of the European Union. Several existing EU instruments contributing to the internationalisation of European businesses may support the purpose of increasing the resilience of energy supply chains, such as:

- Since 2015 the EU has consistently proposed in **Free Trade Agreements**[259] (FTA) dedicated **chapters on energy and raw materials**, such as the EU-Australia FTA[260], the EU-Chile FTA[261], or the EU-Canada Comprehensive and Economic Trade Agreement – article 24.5 on Bilateral dialogue on raw material[262]. These chapters intend to cover aspects which are not covered in WTO rules which could distort the level playing field (such as dual pricing or export monopolies). Then, there are number of regulatory provisions targeted at the energy sector (on third-party access, regulatory independence and oversight, measures on renewable energy for investment certainty, cooperation on standards, permitting) and concerning energy products production (e.g. for EU investments).
- Bilateral agreements with main supplying countries, in the frame of free trade agreements or not (e.g. **EU-Canada Mineral Investment Facility Project**, whose general objective is to support the Raw Materials Initiative objective of guaranteeing access to a secure and sustainable supply of raw materials for the EU industry; the **EU-Japan Centre for Industrial Cooperation**[263] & Support facility for the implementation of EU-Japan EPA; **EU Americas Partnership on Raw Materials**)
- Cooperation through multi-lateral fora and international organisations *(e.g. the Commission already cooperates with partners on critical raw materials and sustainability in a range of international fora, including the annual EU-US-Japan Trilateral on Critical Raw Materials[264], OECD[265], UN[266], WTO[267] and G20[268]).*
- Trade defence measures (e.g. the investigation for and eventual adoption of anti-dumping measures)

Several additional initiatives exist beyond the scope of free trade agreements, like the OECD due diligence guidelines for raw materials, which are used in several circumstances. First, these are used on a voluntary basis, by the industry. Second, the guidelines are referenced in the EU Conflict Minerals Regulation. The Regulation focuses mainly on human rights, but there is a tendency to expand the range of commodities covered by this regulation and to concerns such as environmental impacts and prevention of child labour. Another example is the Batteries Regulation proposal which includes responsible sourcing requirements.

A DG JUST initiative[269] (legislative proposal due by Q2 2021) aims at improving the EU regulatory framework regarding company law and corporate governance. It aims to better align the interests of companies, their shareholders, managers, stakeholders and society and would help companies to better manage sustainability-related matters in their own operations and value chains as regards social and human rights, climate change, and the environment, among others.[270]

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[259] European Commission. (2021). Negotiations and agreements. Available at: https://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/
[260] EU's proposal for the EU-Australia FTA: Draft. (2018). Available at: https://trade.ec.europa.eu/doclib/docs/2018/july/tradoc_157188.pdf
[261] EU proposal for an Energy and Raw materials
Chapter in the Trade Part of a possible modernised EU-Chile Association
Agreement. (n.d.). Available at: https://trade.ec.europa.eu/doclib/docs/2018/february/tradoc_156585.pdf
[262] Comprehensive and Economic Trade Agreement. (2018). CETA chapter by chapter. Available at: https://ec.europa.eu/trade/policy/in-focus/ceta/ceta-chapter-by-chapter/
[263] EU-Japan Centre for Industrial Cooperation. Available at: http://www.eu-japan.eu/
[264] supply risks, trade barriers, innovation and international standards
[265] On conflict minerals, guidance on raw materials, responsible sourcing.
[266] On global outlook, environmental pressures, resource management, mineral governance.
[267] On market access, technical barriers, export restrictions.
[268] On resource efficiency.
[269] European Commission. (n.d.). Sustainable corporate governance. Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12548-Sustainable-corporate-governance
[270] Further details are well summarised in European Parliament (2020). Towards a mandatory EU system of due diligence for supply chains" reminds the basics for binding legislation. Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/659299/EPRS_BRI(2020)659299_EN.pdf

Action 10 of the CRM action plan includes international aspects, that allow to mainstream environmental considerations, which are deemed very important, always look at impacts of domestic and foreign sources. This should lead to define clear rules in horizontal and sectoral legislation (e.g. the extractive waste directive), also concerning e.g. Health, Safety and Environmental risk-based standards. The action 10 could also look at strategic partnerships with developing and developed countries, with the use of socio-environmental criteria to provide assurances.

Policy gaps

Further mainstreaming raw material and energy aspects in the diplomacy and trade arena and in trade policy is an ongoing process. Coalition building and diplomatic outreach may not be systematically directed to factor in measures to increase the resilience of the EU energy system. Trade agreements and policies, although they increasingly tackle the energy and raw material sectors with specific articles, are globally more focusing on the supply of fuels and the production of energy than on securing the supply for critical energy technology chains. Given the identification of several manufactured components for critical supply chains for which the EU is dependent of a concentrated number of external suppliers, there is room to assess whether specific measures are warranted in trade agreements, or whether the more general measures in the agreements are sufficient to assure the supply of components. In addition, the EU may be dependent on a number of suppliers which are based on partner countries with which there is no free trade agreement, and whose trade thus fall under WTO rules.

Necessity and EU added value to act

All identified instruments and initiatives are taken at EU level, and there is a strong commitment of the European Council to building on the EU Climate and Energy policy framework.

However, this EU dynamic should not prevent Member States to tackle the same topics on a bilateral basis with external third parties, although it is considered that an EU action, given the size of the market, the coverage of the low-carbon technologies and the spread of the energy supply chains industry across EU, would be much more efficient than a national standalone action.

Objectives and description of recommendation

Recommendation 2.1: Develop additional coalition building & increasing diplomatic outreach focusing on regions or countries of high importance to the EU critical energy supply chains, like Asian countries, especially China (for several critical raw materials, including rare earths, as well as manufactured components), Japan and the US (for e.g. digital technologies), South Africa (for platinum-group metals), Australia and Chile (for lithium), and the EU-Canada Comprehensive Economic Trade Agreement (under article 25.1 of the CETA[271], the EU and Canada agree to establish and maintain effective cooperation on raw materials issues through the Bilateral Dialogue[272] on Raw Materials, addressed under article 25.4[273]). The European Commission has several instruments / communication channels available for bilateral and multilateral diplomacy related to energy and trade of energy-relevant components and materials. An example is the Trilateral EU-US-Japan Conference on Critical Materials[274]. ENER maintains for example dialogues with a number of countries or regions, like China and the US. Additional involvement in multilateral organizations includes examples such as the Hydrogen Council, to collaborate on the challenges for the hydrogen economy regarding the supply of some materials. Enhanced cooperation with third countries could also be considered, building on a common global concern, such as the worldwide supply of one critical material (e.g. this could be the case for REE which are mainly concentrated in China).

Recommendation 2.2: further mainstream environmental and social (incl. human rights) aspects into trade frameworks such as FTAs and other international frameworks, particularly regarding raw materials which could also be mined within EU. The EU trade with partners needs to be sustainable regarding those aspects in order to mitigate environmental and social impacts in third countries. This concerns not only supply risks but about the conditions on how the materials have been produced.

[271] Lewik. (n.d.). Article 25.1 – Objectives and principles (CETA). Available at: https://www.lewik.org/term/11555/article-251-objectives-and-principles-ceta/

[272] The Bilateral Dialogue on Raw Materials covers issues of mutual interest, including: a forum of discussion to contribute to market access for raw material goods and related services and investments and to avoid non-tariff barriers to trade for raw materials; to exchange information on best-practices and on the Parties' regulatory policies vis-à-vis raw materials; to encourage corporate social responsibility in accordance with internationally-recognised standards ; to facilitate consultation on the Parties' positions in multilateral or plurilateral fora

[273] Lewik. (n.d.) Article 25.4 – Bilateral Dialogue on Raw Materials (CETA). Available at: https://www.lewik.org/term/11558/article-254-bilateral-dialogue-on-raw-materials-ceta/

[274] Ministry of Economy, Trade and Industry. (November 11, 2020). The 10th Trilateral EU-US-Japan Conference on Critical Materials Held. Available at: https://www.meti.go.jp/english/press/2020/1111_001.html

The EC could also integrate these concerns in the frame of multilateral organizations, to complement the previous recommendation 2.1.

Recommendation 2.3: Further adapt the FTA chapters on energy and raw materials concerning aspects related to critical energy supply chains, e.g. amending the RD&I topics to include material substitution, resource efficiency and recyclability, expanding the list of concerned materials to include those identified in this study, and potentially adding to the list other supply chain elements deemed critical (processed materials or manufactured components). Some aspects could also be covered in other dedicated chapters of FTAs. Additional collaboration between TRADE and ENER DGs may be required, such as the draft chapters being submitted to ENER for comments.

It must be noted there are limitations when negotiating FTAs, notably regarding issues which are not sufficiently harmonized within the EU. Issues covered in the FTAs need to be in the EU acquis, as otherwise the competence on the issue would be shared with Member States.

Impact of recommended policy measures

Leveraging EU diplomacy will reinforce the key role it plays in maintaining and strengthening energy security and resilience of the EU, also through anticipating and managing geopolitical risks. By contributing to reinforce the resilience of critical energy technology supply chains, diplomacy action will benefit EU economic actors involved along the supply chain, by strengthening EU economic stability, and investment security. Diplomacy and trade measures can contribute to strengthen coalitions with third parties to address common concerns, like resource depletion or supply concentration, and develop collaboration frameworks and dialogues with specific partners. Trade agreements would directly support Member States and companies with a high vulnerability to mitigate supply risks.

The recommended measure would require coordination between European Commission DGs to ensure the appropriate environmental, social and security concerns and knowledge are taken into consideration when reaching out potential partners to build new coalitions and to support increasing outreach. The administrative cost would therefore remain limited.

The recommended measure would have a global positive impact on EU competitiveness, increasing security and potentially market opportunities. Globally, the recommended measure would have a strong positive cost-benefit ratio given the benefits to increase supply chain resilience, and additional competitiveness of EU companies, and the low additional administrative costs.

Table 3-4 Summary table for recommendation 2

Summary 2. Leverage diplomacy and trade measures	
Measure description	
Description	The objective of this measure is to leverage diplomacy and trade measures by increasing outreach and mainstreaming the energy supply chain critical elements and concerns based on the following recommendations: 2.1: Develop additional coalition building & increasing diplomatic outreach, focusing on regions or countries of high importance to the EU critical energy supply chains 2.2: Further mainstream environmental and social (incl. human rights) aspects into trade frameworks such as free trade agreements and other international frameworks 2.3: Further adapt the free trade agreement chapters under negotiation on energy and raw materials concerning aspects related to critical energy supply chains
Timeline of implementation	• Medium- to long-term
Implementation responsibility	• EU level
Nature of policy action	• Improving current instruments
Existing policy instruments	• Free trade agreements with EU trade partners • Other bilateral agreements with main supplying countries • Cooperation through multi-lateral fora and international organisations • Trade defence measures
Elements of critical supply chains affected	• Critical raw materials • Processed materials and manufactured components, e.g. electrical steel (wind and electricity networks supply chains)
Vulnerabilities	• Concentration of external suppliers, occurring for several critical raw materials and other manufactured components
Related threats and hazards	• **Geo-political tensions** can lead to disruption of supply chains (also caused by an increased use of the same raw material, for possibly the same purpose)
Assessment of the proposed measure	
Impact on the resilience of critical supply chains	• Leveraging EU diplomacy reinforces the key role it plays in maintaining and strengthening energy security and resilience of the EU, also through anticipating and managing geopolitical risks. • Diplomacy and trade measures can contribute to strengthen coalitions with third parties to address common concerns, like resource depletion or supply concentration, • Trade agreements would directly support Member States and companies with a high vulnerability to mitigate supply risks.
Impact on EU competitiveness	• Positive impact on EU competitiveness, increasing security and potentially market opportunities
Cost-benefit ratio	• Positive cost-benefit ratio given the benefits to increase supply chain resilience, and additional competitiveness of EU companies, and the low additional administrative costs.

3.2.3. ***Recommendation 3:*** *Develop EU-based production of raw materials*

Problem description

Moving towards an energy system powered primarily by renewable energy technologies comes with a challenge to secure the required raw materials for these technologies. As shown by the analysis undertaken under this assignment as well as several other analyses[275], the EU is dependent, to a large extent, on a number of critical raw materials mined outside of Europe. Dependence on external suppliers for raw materials introduces vulnerabilities to the supply chain, as any problems associated with external events or geo-political tensions cannot be addressed directly by the EU since they are being outside of the EU's jurisdiction. This is especially true if the external dependence is concentrated in a few suppliers and sourcing choices are limited. Thus, diversification of non-EU suppliers is addressed in the previous recommendation on leveraging diplomacy and trade measures. An additional measure to reduce external dependencies is to increase the domestic production of raw materials in order to exert greater control over the production, distribution and response in the case of unforeseen problems. Of course, the extent to which domestic sourcing of raw materials will be possible is limited by the availability of the raw materials in Europe and also the localisation of raw material deposits, given that not all of them will be accessible for mining-development. Thus, in addition to developing the internal raw material market, other complementary solutions should be developed hand-in-hand to ensure that the strategy to minimise external dependencies on raw

[275] See for e.g. JRC. (2020). Critical Raw Materials for Strategic Technologies and Sectors in the EU – A Foresight Study.

materials is robust and diversified. Measures to develop material and energy efficiency (see recommendation 6 and 7) and material recycling and substitution (see recommendation 7).

Existing policy measures

In 2008, the European Commission adopted the **Raw Materials Initiative**[276]. One of three pillars of this strategy was aimed at ensuring **sustainable supply of raw materials within the EU**. In 2011, a second paper was published in relation to **tackling the challenges in commodity markets and on raw materials**.[277] Within the framework established by these initiatives the Commission has promoted **several measures to minimise external dependence on CRMs**[278] generally and **support investment in the extractive industries in Europe** more specifically. The Commission has promoted the **exchange of best practices** through the publication of **good practice reports**[279], **guidelines on extraction**[280] and the establishment of an ad-hoc expert group on the topic of land use planning and administrative conditions for exploration and extraction.

Additional policy measures in place at the EU-level that support the development of EU-based production of raw materials include the **Copernicus earth observation programme** which has developed the **RawMatCop Programme**[281] aimed at developing skills, expertise, and applications of the Copernicus data to the raw materials sector.

Raw Materials, including their extraction are further addressed under the research programme **Horizon 2020** as part of the Societal Challenge 5 research agenda on "climate action, environment, resource efficiency and raw materials". Horizon 2020 projects such as MIREU[282] helps to establish a network of European mining and metallurgy regions in Europe.

Further, the European Institute of Innovation and Technology (EIT) runs and funds the **EIT RawMaterials**[283] initiative. The innovation themes of the initiative look at activities across the full value chain including exploration and mining of raw materials in addition to downstream activities. More recently, on 3 September 2020 the **European Raw Materials Alliance** (ERMA) was launched as part of the **European Commission's Action Plan on Critical Raw Materials.**[284] The first activities of ERMA will be carried out in clusters dedicated to the specific value chains. The first two clusters will focus on Rare Earth Magnets & Motors and Materials for Energy Storage and Conversion.[285] The European Technology Platform on Sustainable Mineral Resources (ETP SMR) is not directly an EU initiative but rather acts as think-thank to EU affairs concerning the Mineral Resources Industries.

One of the four main aims of the Action Plan on Critical Raw Materials (APCRM) concerns the **strengthening of domestic sourcing of raw materials in the EU**. As part of this aim, four specific actions are highlighted:

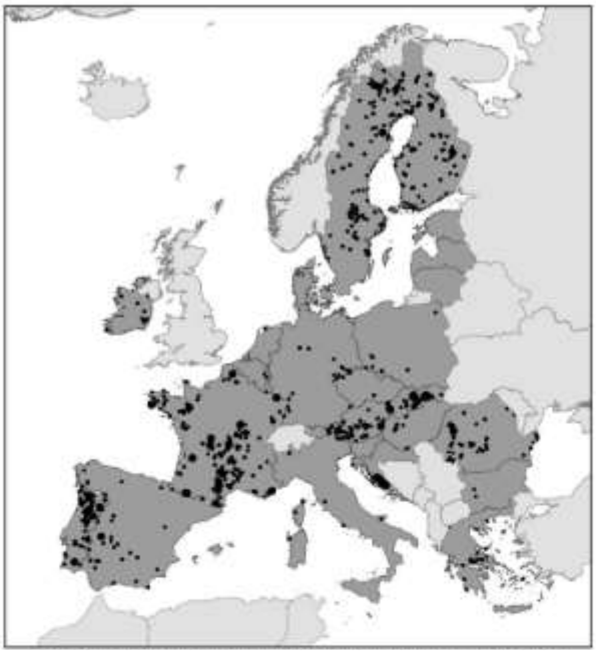
- Identifying mining and processing projects in the EU that can be operational by 2025 with a priority focus on coal-mining regions. In parallel identify investment needs and the related financing opportunities for these projects. (Main actors identified: Commission, Member States, regions, stakeholders)
- Develop expertise and skills in mining, extraction and processing technologies especially in regions in transition from 2022 onwards and as part of a balanced transition strategy. (Main actors identified: Commission, industry, trade unions, Member States and regions)

[276] European Commission. (2008). COM(2008) 699 final. The raw materials initiative -meeting our critical needs for growth and jobs in Europe. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52008DC0699&from=EN
[277] European Commission. (2011). COM(2011) 25 final. Tackling the challenges in commodity markets and on raw materials. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0025&from=EN
[278] For a full list of polices and reports see: European Commission. (n.d.). Critical raw materials. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en
[279] European Commission. (2014). Evaluation and Exchange of Good Practice for the sustainable supply of raw materials within the EU. Available at: https://ec.europa.eu/docsroom/documents/4877/attachments/1/translations/en/renditions/native
[280] European Commission. (2014). Guidance Document: Non-energy mineral extraction and Natura 2000. Available at: https://ec.europa.eu/environment/nature/natura2000/management/docs/neei_n2000_guidance.pdf
[281] EIT RawMaterials. RawMatCop – Europe's eye on raw materials. Available at: https://eitrawmaterials.eu/eit-rm-academy/rawmatcop/
[282] Mining and Metallurgy Regions of EU (MIREU). (n.d.). Available at: https://mireu.eu/
[283] EIT RawMaterials. (n.d.). Available at: https://eitrawmaterials.eu/
[284] European Commission. (2020). COM(2020) 474 final. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability.
[285] European Raw Material Alliance. (2021). Workstreams. Available at: https://erma.eu/workstreams/

- Deploy earth-observation programmes and remote sensing for resource exploration, operations and post-closure environmental management. (Main actors identified: Commission, industry)
- Develop R&I projects under Horizon Europe on exploration processes and processing of critical raw materials to reduce environmental impacts starting in 2021. (Main actors identified: Commission, R&I community)[286]

As highlighted by the first action point above, mining projects for critical raw materials should prioritise regions where coal mining has traditionally been an important activity and where the skills and know-how are already present. For example, the coal-mining region of Silesia, Poland could if cobalt reserves are confirmed, become a good candidate for developing cobalt mining projects given the extensive know-how accumulated in the region through its long history of coal mining.[287] Presently, Finland is the only European country mining cobalt, which is a crucial battery component. However, cobalt resources are also available in Spain and Sweden, while there are unconfirmed amounts in Cyprus, Slovakia, Austria, Czech Republic, Germany, Italy and Poland.[288] Figure 3-3 shows the regions within the EU with critical raw material resource potential. Finland has also raw material deposits of nickel, copper, lithium and graphite, active mining and metallurgical industries and growing manufacturing sector and plans to use these assets to develop battery production capacity.[289] The development of European battery production capacities is facilitated by the EU founded **European Battery Alliance,** which has, as one of its priority actions to secure access to sustainably produced battery raw materials at reasonable cost. Within this priority area, the facilitation of the expansion and creation of European sources of raw materials is highlighted.[290]

Figure 3-3 Critical raw material resource potential in the EU[291]



The analysis of supply chains under chapter 1 (see especially the technology supply chain fiches and T1.2) has highlighted that the transition to a renewable-powered energy system will entail increased demand for certain raw and processed materials. Although the contribution of renewables to tackle climate-change is unquestionable, the increased material demand associated with the growth of

[286] European Commission. (2020). COM(2020) 474 final Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability .
[287] Euractiv. (2020). EU climate transition needs mineral miners not coal miners. Available at: https://www.euractiv.com/section/batteries/news/eu-climate-transition-needs-mineral-miners-not-coal-miners/
[288] JRC. (2018). Cobalt: demand-supply balances in the transition to electric mobility.
[289] Morgan S. for Euractiv. (2020). Finland: Europe's battery producing Shangri-La. Available at: https://www.euractiv.com/section/batteries/news/finland-europes-battery-producing-shangri-la/
[290] European Battery Alliance. (n.d.). Priority Actions. Available at: https://www.eba250.com/actions-projects/priority-actions/
[291] European Commission. (2020). COM(2020) 474 final. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability.

renewables[292][293] could result in environmental and biodiversity related impacts. The mining and processing of minerals is always associated with environmental impacts resulting from ecosystem damage, soil removal, and the use of water, energy and chemicals.[294] In fact, mining waste is already one of the largest waste streams in the EU.[295] In order to regulate the negative impacts of mining by-products the EU has established the **Extractive Waste Directive**.[296] Although, the environmental standards for mining and resource extraction in the EU are often more stringent than in other parts of the world, mining projects in Europe face significant public opposition based on environmental and social concerns.[297] For this reason, ensuring that mining projects have the **social license to operate** has been identified as one of the most crucial success factors across a number of studies.[298] A number of Horizon 2020 projects have focused on societal acceptance of the raw materials sector.[299] This focus should be continued under the **Horizon Europe** programme as specified above for the action on developing R&I project under this programme.

It is important that mining of raw materials in Europe is aligned Commission's pledge to keep resource consumption within planetary boundaries, as set out in the **Circular Economy Action Plan.** Thus, options to minimise material use and increase re-use and development of circular-economy measures should be prioritise when possible (see section 3.2.7). In this context, the work by the JRC on the **recovery of critical and other raw materials from mining waste and landfills**[300] is of relevance**.** Furthermore, development of mining in the EU should be complemented with diplomacy and trade measures (recommendation 2) to at the same time (as developing further domestic capabilities) diversify the sources of imports. These efforts should consider strict environmental and human rights standards[301] that are in line with the EU's internal requirements (see recommendation 2).

Policy gaps

Overall, our assessment concludes that the action points proposed under the **Critical Raw Material Action Plan** in relation to developing raw material production capabilities in the EU are adequate to begin addressing the identified dependencies on raw materials from non-EU suppliers. These actions are also sufficiently focused on the needs of the energy-sector given that, as explained in section 3.1.1, the critical raw materials for the energy sector are largely aligned with those in the 2020 Critical Raw Material List. Our analysis on the critical supply chain elements, including raw materials, for the energy system, complement the information already available based on an economy-wide assessment. The identified **priority raw materials considered** in the programmes of the different initiatives described above are not always explicitly considering the energy system in a systematic way (for example, information on the sectors and raw materials of focus under the EIT RawMaterial is not readily available). As mentioned above, some raw materials identified in this analysis as important for the energy sector such as aluminium (for hydropower, batteries, heat pumps), chromium (for nuclear fission), copper (for wind, PV), nickel (for nuclear fission, batteries), selenium (for PV), tellurium (for PV), zinc (for wind, nuclear fission) are not part of the CRM List and thus likely less monitored (see recommendation 1). Consequently, development of specific mining opportunities within Europe for these materials might be more easily overlooked.

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[292] European Environmental Bureau. (2019). The Renewable Revolution Cannot Occur with Limitless Growth, Experts Warn. Available at: https://meta.eeb.org/2019/12/03/the-renewable-revolution-cannot-occur-with-limitless-growth-experts-warn/
[293] European Environment Agency. (2020). Growth without economic growth. Available at: https://www.eea.europa.eu/publications/growth-without-economic-growth
[294] Manhart et al. (2019). The environmental criticality of primary raw materials – A new methodology to assess global environmental hazard potentials of minerals and metals from mining
[295] European Commission. (n.d.). Mining waste. Available at: https://ec.europa.eu/environment/topics/waste-and-recycling/mining-waste_en
[296] DIRECTIVE 2006/21/EC on the management of waste from extractive industries and amending Directive 2004/35/EC. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02006L0021-20090807
[297] Ibid.
[298]See for example, Ernst & Young. (2015). Top 10 business risks facing mining and metals, 2016-2017. Available at: https://www.yumpu.com/en/document/view/55931669/top-10-business-risks-facing-mining-and-metals-2016-2017
[299] European Commission. (n.d.). EASME – Executive Agency for SMEs. Available at: https://ec.europa.eu/easme/en/workshop-social-acceptance-european-raw-materials-sector
[300] Salminen, J., Garbarino, E., Orveillon, G., Saveyn, H., Mateos Aquilino, V., Llorens González, T., García Polonio, F., Horckmans, L., D`hugues, P., Balomenos, E., Dino, G., De La Feld, M., Mádai, F., Földessy, J., Mucsi, G., Gombkötő, I. and Calleja, I. (2019). Recovery of critical and other raw materials from mining waste and landfills. Blengini, G., Mathieux, F., Mancini, L., Nyberg, M. and Cavaco Viegas, H. editor(s), EUR 29744 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-08568-3 (online),978-92-76-08567-6 (print), doi:10.2760/600775 (online),10.2760/174367 (print), JRC116131.
[301] See for example: Business & Human Rights Resource Centre. (2021). Human rights abuse cannot be the price paid for essential energy transition. Available at: https://www.business-humanrights.org/en/from-us/media-centre/human-rights-abuse-cannot-be-the-price-paid-for-essential-energy-transition/
And Transition Minerals Tracker. Available at: https://trackers.business-humanrights.org/transition-minerals/

The action point under the Critical Raw Materials Action Plan on the identification of mining and processing projects in the EU that can be operational by 2025 with a priority **focus on coal-mining regions should be done in close cooperation with the industry** and in particular industry representing the energy technologies critical for the functioning of the energy system. For example, projects such as the EURARE[302] project developed under the 7th Framework Programme, could benefit from follow up collaborations with the wind industry to evaluate the possibility of rare earth element mining in Europe.

Necessity and EU added value to act

The European Commission has been identified as one of the main actors in the case of all four actions listed above to develop EU-based production of raw materials as part of the CRM Action Plan. Although mineral resource management, permitting and mining legislations are solely in the competence of Member States, the EU has competence in areas relevant for the development of measures to safeguard a well- functioning **internal market** for raw materials. Furthermore according to the Treaty on the Functioning of the European Union (TFEU) the EU and Member States share competences in environment, agriculture and common safety concerns in public health matters (Art. 4 (2)(a)).[303] In addition based on size, the EU will have a better leverage in counteracting external dependencies on critical raw materials as compared to any individual member state.

Actions such as **the Earth-observation programmes** and remote sensing for resource exploration need to be coordinated at EU level in order to have the necessary impact. Furthermore, EU-based instruments, in the form of, for example, funding and knowledge-exchange programmes, will need to be deployed to support the development of EU-based raw material production.

Furthermore, studies such as this one, provide the EU with **knowledge** on the supply chain needs **of the EU energy system** as a whole and thus allow for making decisions which require an overview at EU-level.

Objective and description of recommended policy measure

The objective of this measure is to diminish the current dependence of the EU energy sector on external supplier of raw materials by strengthening the domestic sourcing and raw material production in the EU. This objective can be accomplished, as specified in the CRM Action Plan, through identifying mining and processing projects in the EU, developing expertise and skills in mining, extraction and processing technologies especially in regions in transition, deploying Earth-observation programmes and remote sensing for resource exploration, and support through R&I projects under Horizon Europe on exploration processes and processing of critical raw materials to reduce environmental impacts .Based on the findings of this study, the action points can be further refined to address the needs of the energy sector more specifically. Thus, the recommendations below are aimed at enhancing initiatives already at work with the aim of incorporating the knowledge obtained from this study to refine them.

Recommendation 3.1: Include explicit work on the most critical raw materials for the energy systems into the workstreams of, for example, EIT RawMaterials and, when possible, under the action points from the CRM Action Plan. An explicit programme on CRMs for the energy system would provide better clarity and transparency and could facilitate and be facilitated by enhanced monitoring (see recommendation 1).

Recommendation 3.2: Ensure that EU-based programmes and instruments encourage alignment between the needs of industry and EU-based production of raw materials when identifying mining and processing projects in the EU that can be operational by 2025 through promoting knowledge-sharing and bringing different stakeholders together. The European Battery Alliance, which brings together 600 industrial and innovation actors to focus on developing the battery supply chain including mining to recycling, is a good example of an alliance where industry can provide important information on what are its main needs. This information can be then translated into supporting the most appropriate mining projects. The European Battery Alliance could be replicated for other energy technology supply chains (see section below – on recommendation 4 – Leveraging EU alliances).

Development of communication and public acceptance strategy to increase public acceptance of mining projects in Europe will be paramount to the success of any new mining project in Europe. The European Commission can play an important role in ensuring that that consultation activities and

[302] EURARE. (n.d.). About EURARE. Available at: http://www.eurare.org/about.html

[303] MinPol GMbH et. al. (2017). Study – Legal framework for mineral extraction and permitting procedures for exploration and exploitation in the EU. Available at: https://op.europa.eu/en/publication-detail/-/publication/18c19395-6dbf-11e7-b2f2-01aa75ed71a1/language-en

public awareness campaigns are developed. Furthermore, **close alignment between energy and environmental policies as well as human rights protection** will be important to develop coherent initiatives backed by the public opinion. Furthermore, mining in Europe by itself will not be sufficient to fully address external dependencies on CRMs, and the environmental and social limitations described above. Hence, this measure should be an element of a broader approach based on diplomacy, market diversification and research on enhance material efficiency and circularity approaches.

Impact of recommended policy measure

The intended impact of the recommended policy measures is to ensure that the work on developing EU-based production of raw materials is aligned between the economy-wide needs and those of the energy sector specifically. These measures should ensure that mining projects considered will correspond to the needs of industry and will be useful to reduce the vulnerabilities in the energy technology supply chains associated with high dependence on external sourcing of raw materials.

More generally, reducing external dependency on raw materials from non-EU suppliers will make the supply chains of energy technologies more resilient to external disruptions. In addition, a secondary, positive impact of policies aimed at developing EU-based production of raw materials will be the creation of jobs and, when possible, support for the transition of coal-mining regions to production activities aligned with the EU 2050 climate neutrality ambitions.

Furthermore domestic mining of raw materials in the EU will allow to have better control on the environmental and societal conditions under which resource extraction takes place. The EU should exert its diplomatic leverage to ensure that extraction in non-EU countries also follows high levels of environmental and social standards. It is important to highlight that inadequate polices could result in negative environmental and societal impacts for the EU.

Table 3-5 Summary table for recommendation 3

Summary – 3. Develop EU-based production of raw materials	
Measure description	
Description	The objective of this measure is to diminish the current dependence of the EU energy sector on external supplier of raw materials by strengthening the domestic sourcing and raw material production in the EU based on the following recommendations: Recommendation 3.1: Include explicit work on the most critical raw materials for the energy systems into the workstreams of the different EU initiatives such as, for example, EIT Raw Materials and, when possible, under the action points from the CRM Action Plan. Recommendation 3.2: Ensure that EU-based programmes and instruments encourage alignment between the needs of industry and EU-based production of raw materials when identifying mining and processing projects in the EU that can be operational by 2025 through promoting knowledge-sharing and bringing different stakeholders together.
Timeline of implementation	• Short term, by 2025
Implementation responsibility	• EU-level, Member State – level (mining competency)
Nature of policy action	• Maintaining existing policy instruments
Existing policy instruments	• Critical Raw Materials Action Plan • Horizon2020, Horizon Europe • EIT RawMaterials, ERMA • Copernicus earth observation programme
Elements of critical supply chains affected	• Raw materials supply chain stage
Vulnerabilities	• Import dependency on non-EU suppliers, high market concentration
Vulnerable EU regions / Member States	• Critical supply chains where risk management by entities would be beneficial present in all EU Member States. Certain supply chains more important in specific regions (e.g. wind and solar PV), while others such as electricity networks are relevant to all Member States (especially considering developments to 2050.
Related threats and hazards	• Geopolitical tensions, extreme weather events, persistent pandemics
Assessment of the proposed measure	
Impact on the resilience of critical supply chains	• Positive, through diminished reliance on external sourcing
Impact on EU competitiveness	• Positive, through job creation, development of e.g. coal-regions in transition, strengthening of the internal market for raw materials.
Cost-benefit ratio	• Undetermined. There are substantial costs associated with the development of mining projects in the EU. The beneficial impacts in supply chain resilience and EU competitiveness are stated above.
Best practices	
Best practices	• Non-Energy Mineral Extraction in Relation to Natura 2000 – Case Studies. Available at: https://ec.europa.eu/environment/nature/natura2000/management/docs/NEEI%20case%20studies%20-%20Final%20booklet.pdf • https://www.remindproject.eu/#rs-about • The environmental criticality of primary raw materials – A new methodology to assess global environmental hazard potentials of minerals and metals from mining

*3.2.4. **Recommendation 4:** Leverage EU alliances to address supply chain risks*

Problem area description

This recommendation addresses the problem that **for some critical energy technology supply chains there is limited EU manufacturing for certain vulnerable components, which contributes to an external dependence on a limited number of non-EU suppliers and/or specific world regions**. For example, the EU has a high import reliance for solar PV cells and modules, as well as several components required for the manufacturing of batteries, including Li-ion cells, cathode, anode, electrolyte and separators. International supply chains can bring about benefits such as keeping costs low for EU companies, supporting supplier diversification, and contributing to EU manufacturers having access to global markets. However, external dependence when coupled with supplier concentration, as is the case for numerous vulnerable components, increases the vulnerability of the EU energy technology supply chains to various threats.

Regarding the hydrogen fuel cells, the stack design and cell assembly EU market share was very low in the period 2014-2017[304], and the activity deemed critical for the EU. But the activity has evolved rapidly these last years, as more and more hydrogen players are developing stack design and cell assembly across Europe. However, despite the EU players listed under chapter 1, as there is currently no evidence that stack design and cell assembly is no longer a weakness for the EU, this should be monitored closely, certainly in the frame of the European Clean Hydrogen Alliance.

Ideally, existing vulnerabilities for critical energy technology supply chains should be addressed by industry-led initiatives. It is in the interest of EU companies to address these vulnerabilities and further develop the EU industry. However, there may be a number of barriers whereby industry initiative would be insufficient to address high external dependence for certain vulnerable components. Such barriers may include the lack of information on vulnerable components' supply chains, coordination difficulties between EU companies, difficulties in EU companies appropriating benefits of R&I (i.e. positive externalities of R&I), difficulties in addressing the issue of supplier and/or market concentration in the sourcing of specific raw and processed materials that are natural resource endowments concentrated in specific countries, and the high cost of capital and other manufacturing inputs.

Existing policy instruments

A number of sectoral alliances for developing EU industry exist which should contribute to reducing the vulnerability of critical energy technology supply chains. The **European Battery Alliance (EBA)** and **European Clean Hydrogen Alliance (ECH2A)** have been established to facilitate strong cooperation and joint action between various stakeholders across the value chains within the EU. The **Smart Buildings Alliance (SBA)** started in France and involves the major EU sector players, being now expanded to several other Member States (BE, DE, IT, NL). In late 2020, 20 Member States signed a joint declaration to strengthen the **EU electronics and embedded systems value chain**, where one of the stated objectives is the establishment of a future industrial alliance.[305] Moreover, a number of industry associations exist which are actively working towards addressing challenges to the development of EU industry for related critical supply chains or components, such as FORATOM (for the nuclear industry) and EUROFER (for the steel industry).

As part of the new European Industrial Strategy announced in March 2020 (COM(2020) 102[306]) and updated in May 2021[307], **alliances on low-carbon industries** will also be launched[308]. Also part of the Industrial Strategy, the EU **Industrial Forum aims** to support the Commission in the "systematic analysis of the different industrial ecosystems and in assessing the different risks and needs of industry" and held its first meeting in February 2021.[309]

In addition, cross-sectoral alliances impacting several of the critical supply chains identified in this study exist. The **European Raw Materials Alliance (ERMA)** has been established to monitor the usage of critical raw materials, and the status of their criticality, and propose actions to ensure a reliable, secure, and sustainable access to critical and strategic raw & processed materials. ERMA is further discussed in recommendation 3. Moreover, a number of other platforms and associations exist which can directly or indirectly contribute to the development of the EU industry for critical supply chains. The **European Energy Research Alliance (EERA)** was set up to accelerate the development of new energy technologies by aligning research and development activities across the EU. Its members are mainly research organisations, although some companies also participate. Also, Energy Technology and Innovation Platforms (ETIPs) exist, covering many of the critical energy technology supply chains (e.g. for wind, solar PV, nuclear, and bioenergy) and developing strategic research agendas for the technologies. Such alliances can help to increase the resilience and global competitiveness of these supply chains at the EU level and complement industrial alliances.

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[304] The stack design and cell assembly market share in 2014-2017 of the Fuel Cell System Manufacturing shows Europe's share reaching ~1% of the global.

[305] European Commission - Joint declaration on processors and semiconductor technologies, industrial alliance on semiconductors

[306] European Commission. (March 10, 2020). Making Europe's businesses future-ready: A new Industrial Strategy for a globally competitive, green and digital Europe. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_416

[307] European Commission. (n.d.). European industrial strategy. Available at: https://ec.europa.eu/growth/industry/policy_en

[308] European Commission. (March 10, 2020). Making Europe's businesses future-ready: A new Industrial Strategy for a globally competitive, green and digital Europe. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_416

[309] European Commission. (n.d.). Industrial policy dialogue and expert advice. Available at: https://ec.europa.eu/growth/industry/policy/dialogue-expert-advice_en

Funding instruments: As discussed above, industrial alliances can help increase the competitiveness and resilience of EU's renewable energy technology industries. Given the strategic opportunities that such alliances can provide to the EU, the use of EU-level funding can be supported, such as through the Important Project of Common European Interest (IPCEI) instrument. The IPCEI instrument can be utilised under EU's state aid rules to help stimulate investments and materialise innovations and initiatives within strategic value chains in the EU. Such an instrument enables Member States to fill in the gap, which helps to overcome the risks that are too significant for private undertaking, while helping to realise projects that can bring large benefits to the EU economy, and is careful to limit aid to companies so as to minimize distortions to competition. For example in January 2021, the EU had approved, under EU state aid rules, its second pan-European Important Project of Common European Interest (IPCEI) for the "European Battery Innovation" project. This project supports R&I in the battery value chain, and will receive €2.9 billion of public funding over the coming years, while also expecting to stimulate €9 billion in private investments. Also in 2020, an IPCEI on hydrogen has been launched, while other projects in the field of microelectronics and communication technologies and for the development of an industrial cloud are in the pipelines to be launched.

The InvestEU Programme[310], while helping the EU economy to recover from the COVID-19 crisis, aims to give an additional boost to investment, innovation and job creation in Europe over the period 2021-27, by triggering a new wave in investments using an EU budget guarantee. The InvestEU programme aims to playing a pivotal role under the European Green Deal Investment Plan (EGDIP[311]), which was adopted by the European Commission on January 2020 - the financial pillar of the European Green Deal. It aims to mobilise public and private financial resources to support around €1 trillion in green investment over the next decade while ensuring a just transition issues. At least 30% of the InvestEU Programme, in line with the European Green Deal objectives, will support financing for investments that contribute to EU's climate objectives. Alliances can guide and channel investments and funding in this framework.

The Recovery and Resilience Facility[312] will make available €672.5 billion in loans and grants to support reforms and investments undertaken by Member States. The aim is to "mitigate the economic and social impact of the coronavirus pandemic and make European economies and societies more sustainable, resilient and better prepared for the challenges and opportunities of the green and digital transitions". The Commission will assess recovery and resilience national plans to ensure: a minimum of 37% for climate investments and reforms, and a minimum of 20% to foster the digital transition. Alliances could also probably guide and channel investments and funding for national plans.

Further, alliances can also provide a channel for investments to advance on strategic objectives at the EU level. For example, one of the two workstreams of the ERMA is to make a selection and prioritisation of investment cases, and match them with the most suitable source of financing, through grants, equities, loans, or a mix of these financing instruments. However, given the strong component of financing to support the work of alliances, the forming of new EU alliances should be scrutinised and be focused on new technologies. As a member of the WTO, the EU is also obliged to abide by the Agreement on Subsidy and Countervailing Measures. The forming of alliances for existing technologies could create an unfair competitive advantage towards EU companies, and third countries can take anti-dumping or other trade measures against the EU.

Strategic vulnerabilities and high-risk dependencies which could jeopardize the attainment of the EU clean energy transition, need to be addressed through diplomacy in a tailored approach (see 3.2.2 on Recommendation 2) in order to strengthen EU open strategic autonomy and resilience. Diplomatic efforts can complement the strengthening and development of EU industrial alliances, and can help to increase the resilience of energy technology supply chains by reducing risks from material and product supplies which cannot be sourced within the EU, increasing diversification and by providing a level-playing field for the EU industry.

Policy gap

Industrial alliances can help to identify key objectives and prioritise actions required to develop the industry, especially for new and emerging technologies or products where EU companies are not yet world leaders. It can bring together various stakeholders including national authorities, industrial and

[310] InvestEU. (n.d.). InvestEU. Available at: https://europa.eu/investeu/home_en

[311] Also referred to as Sustainable Europe Investment Plan (SEIP). InvestEU. (n.d.). Contribution to the Green Deal and the Just Transition Scheme. Available at: https://europa.eu/investeu/contribution-green-deal-and-just-transition-scheme_en

[312] European Commission. (n.d.). Recovery and Resilience Facility. Available at: https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en

research actors to develop a resilient, sustainable and competitive value chain by identifying concrete industry initiatives such as the establishment of manufacturing facilities in the EU.

Three existing industrial alliances have been identified for critical energy technology supply chains of this study (European Battery Alliance, European Clean Hydrogen Alliance, and Smart Buildings Alliance). For these existing alliances, it is necessary to maintain efforts to develop the respective EU industry, with cooperation of all relevant stakeholders. Moreover, the planned establishment of an industrial alliance for semiconductors will help addressing the external dependence of the digital technologies supply chain, which is important for all critical supply chains identified in this study.

Industrial alliances should also leverage their position to create opportunities for EU companies in third country markets, which can be executed through dedicated SME chapters in Free Trade Agreements, for example. Further, alliances can also strengthen the resilience of EU industries through facilitating closer collaboration and fostering stronger partnerships with third countries, such as through multi-lateral discussion and dialogue platforms.

Necessity and EU added value to act

EU industry is a leader for several critical energy technologies supply chains, but also faces a number of challenges for certain components which warrant the development of industrial strategies and associated actions to develop EU-based manufacturing. The development of strategies and the underlying actions at the EU level is justified by a number of reasons:

- The **integration of the EU internal market and the cross-border nature of several critical supply chains** means neither of these supply chains nor demand markets are restricted to individual Member States, with the internal market being a shared competence between the EU and Member States;
- The relevance of other **areas for industrial policy which are shared or exclusive EU competences**, including commercial policy, the customs union, research, and energy;
- The need for coordination between stakeholders not only at the national but also the EU and international level, including EU-level industry associations which should be directly involved in developing strategies for the relevant critical supply chain.

Objective and description of recommended policy measure

The objective of this measure is the strengthening of existing alliances, and identifying the need for and developing alliances for other critical supply chains if warranted, while abiding by WTO rules. This should also be complemented by identifying the need to develop a comprehensive and coordinated approach to coalition-building and diplomatic outreach to specific partners, including through the network of EU delegations (see recommendation 2 on diplomacy and trade).

Recommendation 4.1: Ensure existing EU alliances contribute to increasing the resilience of critical energy supply chains – where relevant, and address more systematically supply risks and exposure to threats, and international trade relationships.

Existing alliances comprise specifically the European Battery Alliance (EBA) and the European Clean Hydrogen Alliance. For the EBA there are no specific recommendations, while for the Clean Hydrogen Alliance the following specific recommendations may be considered:

- There are currently six thematic roundtables (or working groups) responsible for the ECH2A[313]'s operational work. They are in charge of building a thematic pipeline of scale-up projects and the investment agenda in their area, while ensuring the interdependence with the other round tables. When relevant to their mission, they may also flag obstacles and bottlenecks for the upscaling of hydrogen, provide input to the work on regulations, standardisation, and research and innovation priorities. Although there is no specific Roundtable to address transversal issues (like supply risks), this will be mainly dealt in Roundtables Production and Mobility in relation with the equipment manufacturing projects. When the project collection is launched, project promoters will have the opportunity to detail which are the potential bottlenecks, and the supply dimension will be specifically taken on board. The Alliance works began in March 2021 under the responsibility of the Unit Energy Intensive Industries & Raw materials, therefore more integration of the supply dimension in the hydrogen value chain is expected. As there is no specific action on addressing the risks on the supply chains, the upscaling assessment Roundtables Production and Mobility should ideally address the identified vulnerable components (e.g. addressing EU supply, manufacturing, substitution and/or recycling, bilateral and multilateral trade agreements with supplying countries and regions)

[313] European Commission. (n.d.). Roundtables of the European Clean Hydrogen Alliance. Available at: https://ec.europa.eu/growth/industry/policy/european-clean-hydrogen-alliance/roundtables_en

Given the strong position of EU players in the sector, the focus of the Smart Buildings Alliance should be on maintaining the EU leadership and eventually covering identified gaps (such as for home energy management software), while the battery and hydrogen alliances should focus on the growth of their sectors and placing EU companies in a leading position.

Recommendation 4.2: Consider candidates for new alliances or adaptation of the scope of existing alliances. However, such alliances should be preferentially focused on emerging technologies and applications, hence especially battery and hydrogen. Other potential alliances for mature technologies such as for semiconductors should avoid subsidies infringing WTO rules.

In the case a new alliance should be considered (to address a specific application for hard-to-abate sectors, or for an emerging and promising technology), the EU Industrial Forum remains the appropriate platform for confirming the need for such alliances. Following an ecosystem analysis for several industries, the Forum is due to meet in November 2021 to make recommendations for implementation of the European Industrial Strategy.[314] The Forum could include smart buildings in its ecosystem analysis. There is already a Smart Buildings Alliance, which has so far had a French focus, with national chapters being currently set-up in other countries. Its scope should be expanded to cover the EU or, alternatively, another industrial alliance at the EU level should be set-up to foster industrial initiatives in the sector. This should be founded on the identification of a clear need for such an alliance, based on the Industrial Forum analysis of industrial eco-systems.

EU alliances should collaborate with EU and national actors to develop sectoral industrial strategies, implementing actions focused on developing EU-based manufacturing. Further, industry alliances can also assess risks for their supply chains and thus increase the resilience of the critical energy technology supply chains. Also, alliances can support the development of EU regulatory and non-regulatory policy measures by the provision of expert knowledge. This includes diplomacy and defence measures such as:

- Free Trade Agreements;
- Bilateral agreements with main supplying countries (e.g. by addressing important material sourcing with China);
- Cooperation through multi-lateral fora and international organisations (e.g. by addressing material concentrated in Asian countries);
- Restoring a level-playing field for trade in goods and investments (e.g. by the provision of information to investigations supporting the implementation of anti-dumping measures).

Impact of recommended policy measure

Developing EU-based industries would help to ensure that EU companies have access to a more secure supply of critical elements. If the alliances are successful, they could develop EU sources for e.g. electrical steel, PV cells and modules, battery components and more. This would reduce the EU external dependence on these vulnerable components and increase supplier diversification, allowing EU manufacturers to choose from a larger number of EU and non-EU suppliers. The successful development of EU industry for these and other components has a number of additional direct and indirect benefits, including positive impacts on growth and employment, EU technological leadership, and innovation spillovers to other sectors. In addition, it also provides a platform for actions developing demand markets for the low carbon energy technologies, further strengthening EU industry, as well as supporting EU trade and defence measures. Such alliances can facilitate and strengthen cooperation between various stakeholders at different levels across the EU and across stakeholder categories, including authorities, industry and their associations, consumers and others.

Industrial alliances do have an associated administrative cost as well as other costs associated with implementing the actions for developing the industry, such as financing and R&I costs (from private and public funds), as well as other government expenditures for economic support. Moreover, there is a risk that new industrial alliances increase coordination costs, especially if significant overlaps exist with other initiatives taken for example by existing industrial associations and the actors collaborating within the ETIPs. Therefore, the establishment of industrial alliances must be supported by a preliminary analysis of the benefits and costs of such initiatives, with the Industrial Forum being the most appropriate platform for conducting such analysis.

[314] DG GROW. (2021). First Meeting of the Industrial Forum – Minutes.
https://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupMeetingDoc&docid=47976

Table 3-6 Summary table for recommendation 4

Summary – 4. Leverage EU alliances to address supply chain risks	
Measure description	
Description	The objective of this measure is to strengthen existing alliances, and identify the need for and develop alliances for other critical supply chains if warranted, based on the following recommendations: Recommendation 4.1: Ensure existing EU alliances contribute to increasing the resilience of critical energy supply chains – where relevant, and address more systematically supply risks and exposure to threats, and international trade relationships. Recommendation 4.2: Consider candidates for new alliances or adaptation of the scope of existing alliances. However, such alliances should be preferentially focused on emerging technologies and applications, hence especially battery and hydrogen. Other potential alliances for mature technologies such as for semiconductors should avoid subsidies infringing WTO rules.
Timeline of implementation	• Short-term (existing alliances) • Mid-term (eventual new alliances)
Implementation responsibility	• EU-level
Nature of policy action	• Maintaining existing policy instruments
Existing policy instruments	• European Battery Alliance (EBA) • European Clean Hydrogen Alliance (ECH2A) • Smart Buildings Alliance (SBA) – national level, expanding in additional countries • Planned: future EU semiconductors alliance • Free Trade Agreements • Bilateral agreements with main supplying countries • Cooperation through multi-lateral fora and international organisations • Restoring a level-playing field for trade in goods and investments (e.g. through anti-dumping measures)
Elements of critical supply chains affected	• Li-ion cells, cathode, anode, electrolyte, separator (battery supply chain) • Fuel cell materials (hydrogen supply chain) • PV cells and modules (solar PV supply chain) • Electrical steel (wind and electricity networks supply chain)
Vulnerabilities	• Dependence on non-EU suppliers, with limited EU-based manufacturing
Vulnerable EU regions / Member States	• While the measure would benefit the EU in general, supply chains in specific regions or Member States may be impacted to different extents. For example, FR and DE are leaders in smart buildings supply chains, and current EU manufacturers of electrical steel are based in CZ, DE and HU.
Related threats and hazards	• Extreme weather events, geo-political tensions and persistent pandemics
Assessment of the proposed measure	
Impact on the resilience of critical supply chains	• Positive, should help in securing access to supplies of raw and processed materials; • Should reduce EU's external dependence on some of the vulnerable components, and increase supplier diversification; • Can lead to positive impacts on growth and employment, EU technological leadership, and innovation spillovers to other sectors
Impact on EU competitiveness	• Positive, through job creation, development of markets for energy technologies; • Promotion of innovation to remain as one of the global leaders of renewable energy technologies; • Development of new initiatives to support the growth of energy technologies at a pace in line with EU's climate ambitions
Cost-benefit ratio	• Positive, although the setting up of new alliances would have associated administrative costs, and would require further investments from the EU, there are many beneficial outcomes to improve supply chain resilience and EU competitiveness as stated above.
Best practices	
Best practices	• Existing European Battery and Clean Hydrogen Alliances

3.2.5. **Recommendation 5:** *Improve risk assessment and management by relevant entities*

Problem area description

This recommendation addresses the problem that **EU companies in critical energy technology supply chains and the technology users may not be fully aware of vulnerabilities and threats stemming from the supply chains, and may not have developed mitigation and emergency measures**. This applies to all threats, including cyber threats.

Businesses generally have continuity plans and supply chain strategies in place, with supplier management processes considering requirements of ISO and other standards[315]. The feedback and interviews received from stakeholders confirm that companies often have business continuity plans, but are not necessarily aware of the potential impacts of long-term or systemic risks on their supply chains, such as extreme weather events, cyber threats or geo-political tensions, nor have taken measures to mitigate those risks. Hence, improvements can be made regarding the consideration of risks such as cyber threats arising from sourced products and services, and geo-political tensions or extreme weather events limiting exports of components with highly-concentrated supply. Small and medium enterprises especially may lack the capacity to conduct appropriate supply chain management processes covering the main relevant risks, while large (multinational) companies generally conduct those already.

Existing policy instruments

The **Commission Report on the "Progress of Clean Energy Competitiveness**" and the supporting "Clean Energy Transition – Technologies and Innovations" report[316], to be published on an annual basis, have the right focus on assessing supply chains. However, its unit of analysis is an entire EU energy technology supply chain rather than individual companies. Even with high-level supply chain monitoring exercises such as the Clean Energy Competitiveness reports, the conditions of each company will be highly specific, as companies focus on certain markets, product types and technologies, and depend on certain strategic suppliers. Higher-level reports by the Commission and other organisations can help companies identify and address their own risks. Thus, efforts by companies to manage their supply chains and minimise risks complement actions taken by the EU, national governments and industry associations.

There is already a number of existing or proposed EU policy instruments establishing requirements for regulated and private energy asset operators in the EU.

The **Council Directive on protecting Critical Infrastructures**[317] establishes requirements for identifying and designating European Critical Infrastructures, and for developing operator security plans for it. In December 2020 the European Commission published a proposal for a **Directive on the Resilience of Critical Entities**[318] (CER Directive), which would replace the Council Directive on protecting Critical Infrastructures. Article 11(1) of the CER Directive proposal establishes a requirement for assuring that critical entities take measures to increase their resilience, including in order to 'recover from incidents, including business continuity measures and the identification of alternative supply chains'. Furthermore, proposed Article 11(5) indicates the Commission 'shall adopt implementing acts in order to set out the necessary technical and methodological specifications relating to the application of the measures referred to in paragraph 1'. The CER Directive critical energy entities comprise regulated and private operators of electricity, gas (including hydrogen), and district heating and cooling assets.

There are sectoral security of supply planning obligations for Member States concerning electricity and gas. Under the **Regulation on Risk-preparedness in the Electricity Sector**[319] Member States need to establish risk-preparedness plans for the sector in consultation with sectoral stakeholders, addressing at least risks of extreme natural hazards (in the Member State), 'accidental hazards going beyond the N-1 security criterion and exceptional contingencies', and other hazards such as malicious attacks and fuel shortages. Under the **Regulation on Security of Gas Supply**[320] Member States should prepare preventive action plans and emergency plans in consultation with sectoral stakeholders. The minimum list of risks to be considered include political risks (concerning gas supply), technological risks (including ICT failure and cyber attacks), natural hazards, and commercial/market/financial risks.

The first **Directive on the Security of Networks and Information Systems**[321] (NIS Directive) requires Member States to ensure that 'operators of essential services take appropriate measures to

[315] For example in ISO 9001:2015 (quality management systems) or ISO 28000:2007 (Specification for security management systems for the supply chain)
[316] European Commission. (2020). SWD(2020) 953 final. Clean Energy Transition – Technologies and Innovations. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0953
[317] Council Directive 2008/114/EC on the Identification and Designation of European Critical Infrastructures and the Assessment of the Need to Improve Their Protection.
[318] European Commission. (2020). COM(2020) 829 final. Proposal for a Directive on the European Parliament and the Council on the resilience of critical entities. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:829:FIN
[319] Regulation (EU) 2019/941 on Risk-preparedness in the Electricity Sector
[320] Regulation (EU) 2017/1938 Concerning Measures to Safeguard the Security of Gas Supply
[321] Directive (EU) 2016/1148 Concerning Measures for a High Common Level of Security of Network and Information Systems Across the Union

prevent and minimise the impact of incidents affecting the security of the network and information systems used for the provision of such essential services, with a view to ensuring the continuity of those services' (Art. 14(2)). The proposed **revised Directive on Security of Network and Information Systems**[322] **(NIS 2 Directive)** requires Member States to ensure that essential and important entities take risk management measures, including to address supply chain security risks concerning its products and service providers. The Commission may adopt implementing acts to detail the methodology for Art. 18(2), which contains the mentioned requirement. As for the CER Directive, relevant entities in the energy sector comprise regulated and private operators of electricity, gas (including hydrogen), and district heating and cooling assets.

In addition, a number of EU policy and regulatory instruments aim to increase the cybersecurity of the energy sector. These are presented in Textbox 3-2. Particularly, ACER's Draft Framework Guidelines for the development of the upcoming **network code on sector-specific rules for cyber security aspects of cross-border electricity flows** includes requirements for supply chain security and cybersecurity certification of components.[323]

A number of **due diligence guidelines** exist already, but their focus is not to increase the resilience of EU energy technology supply chains. In 2020 the European Commission published the roadmap for an initiative on Sustainable Corporate Governance, aiming to update the EU regulatory framework to "help companies to better manage sustainability-related matters in their own operations and value chains as regards social and human rights, climate change, environment, etc."[324] The inception impact assessment explicitly indicates that such an initiative could increase the resilience of the supply chains to external shocks, such as COVID-19. Nonetheless, the primary focus remains on social and environmental aspects. The 2021 Commission Guidance to Member States on developing recovery and resilience plans[325] also states the plans should indicate how they will contribute to increase the resilience of supply chains of the Member State in question. Other relevant guidelines include also the OECD Due Diligence Guidance for Responsible Business Conduct.[326]

Policy gap

Currently, companies in the EU energy sector assess technology supply chain risks and develop mitigation measures only to a certain extent. The risk assessment and mitigation measures may be insufficient especially for systemic risks and for small and medium enterprises.

Relevant work is ongoing to understand energy technology supply chains at the EU and national level in order to support the design of policy measures aiming to increase their resilience. This concerns particularly the Commission's "Clean Energy Transition – Technologies and Innovations" report work. EU-level supply chain monitoring actions are detailed in recommendation 1. Such initiatives can help inform company-level decisions, but are nonetheless looking at an entire supply chain and have an EU scope (which can help to better assess systemic risks).

However, EU policy instruments in force do not explicitly require or incentivise companies to assess and mitigate supply chain-related risks, although instruments do exist to increase the resilience of the energy and other critical entities in general. Energy sector companies may voluntarily conduct supply chain-related risk assessments and implement mitigation measures. National regulation complementing EU instruments may also require companies to do so. Therefore, vulnerabilities regarding e.g. external dependence on products for solar PV, batteries, electricity networks and wind power components, or supply chain-related cyber-security of energy networks may be mitigated in this way. But EU policy measures explicitly requiring or incentivising supply chain-related risk assessment and mitigation at the company level would still be beneficial. This need for EU level measures should be to a significant extent covered by the on-going policy & regulatory developments mentioned in the overview of policy instruments.

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[322] European Commission. (2020). Proposal for a Directive on Measures for a High Common Level of Cybersecurity Across the Union. Available at: https://digital-strategy.ec.europa.eu/en/library/proposal-directive-measures-high-common-level-cybersecurity-across-union

[323] ACER. (2021). Framework Guideline on sector-specific rules for cybersecurity aspects of cross-border electricity flows (Draft). Available at: https://documents.acer.europa.eu/Official_documents/Public_consultations/PC_2021_E_04/Draft%20Framework%20Guideline%20on%20sector-specific%20rules%20for%20cybersecurity%20aspects%20of%20cross-border%20electricity%20flows.pdf

[324] European Commission. (n.d.). Sustainable Corporate Governance. Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12548-Sustainable-corporate-governance

[325] European Commission. (2021). SWD(2021) 12 final. Guidance to Member States – Recovery and Resilience Plans.

[326] OECD. (2018). OECD Due Diligence Guidance for Responsible Business Conduct. Available at: https://mneguidelines.oecd.org/OECD-Due-Diligence-Guidance-for-Responsible-Business-Conduct.pdf

Necessity and EU added value to act

The intervention at the EU level would lead to a harmonised approach in the assessment of the critical energy technology supply chains across Member States and application of a methodology for identifying mitigation measures. A harmonised approach is justified by the highly integrated nature of the internal energy market, the cross-border nature of EU energy technology supply chains and the common vulnerabilities across Member States regarding e.g. dependence on non-EU suppliers for materials and components.

The recommendation would be proportional, especially if focusing on the most important operators, thus limiting the administrative burden to the most important entities in the energy sector. Any measures would need to address extra-territoriality concerns of companies based outside of the EU, as any binding requirements could directly apply to them. Nonetheless, they could apply to products sold on the EU market and requirements to EU-based companies could have a positive upstream effect as those companies could incorporate resilience measures in their supplier relationships, including with non-EU suppliers.

Objective and description of recommended policy measure

Recommendation 5.1: Provide a guidance for EU energy companies assessing and managing supply chain-related risks. This guidance would detail the methodology as well as provide examples of how to assess technology supply chains. The recommendations could be incorporated by companies within their business continuity plans as well as other measures.

Examples of the content of the guidance could include:

- The structuring of supply chains, defining all supply chain stages from raw materials sourcing to component manufacturing, transport, construction, O&M and decommissioning/recycling;
- The potential supply chain vulnerabilities along with example indicators which could be employed to quantify those vulnerabilities;
- The list of potential threats and specific hazards to assess, including all the ones considered in the present study;
- A methodology to assess the impact of certain threat scenarios on the company's operation, considering the identified vulnerabilities, including the application of stress tests;
- Potential measures that could be adopted by companies to increase resilience, including a reliability criteria such as a residual supplier index threshold, or strategic reserves;
- A list of existing resources at the EU or national level which could be employed by companies, such as published reports, relevant authorities as well as best practice examples.

The Commission guidance should be high-level and provide enough flexibility to fit each situation. This guidance could apply both to existing company operations as well as to future projects, in order to anticipate potential vulnerabilities and threats in fast-growing energy sectors. The guidance should also specifically address the issue of supplier relationships, so that best practices in risk assessment and management by EU companies extends upstream in the supply chain, including to non-EU suppliers.

Recommendation 5.2: Leverage the CER and NIS 2 Directive proposals to ensure relevant entities conduct the risk assessment and implement corresponding measures. The CER and the NIS 2 Directives proposals do contain specific requirements for relevant entities to do so, and furthermore require or empower the Commission to detail the methodology for complying with those requirements through implementing acts.

Given the definition of relevant entities in these legislative proposals, the requirements would apply to the most important energy asset operators in the EU for almost all critical supply chains in this study. For all critical supply chains some operators may not be required to assess risks and develop contingency measures potentially reducing the requirement coverage, depending on how the Directive is transposed by each Member State and how those identify the critical entities. But the most important operators in most supply chains would fall under the definition of critical / relevant entities, and obligations for suppliers and aggregators could extend the impact of the requirements also to 'end-use' technologies such as smart buildings, battery EVs and behind-the-meter solar PV.

The CER and NIS 2 Directive supply chain requirements would apply to the operators of existing assets, but not to future technology deployment projects. Companies could be encouraged to voluntarily include the management of project risks in their plans. In the future, an ex-post evaluation of the Directives could inform if a forward-looking component (i.e. including a risk assessment for company projects) is warranted in a possible revision.

Impact of recommended policy measure

The recommendations would help energy asset operators to assess risks and consider mitigation measures, for example in sourcing components for EV batteries, electrical steel for electricity networks and wind turbine transformers, and control systems and 3rd party services for the operation of electricity and gas networks. This would apply especially to hazards overlooked by actors (extreme weather events and geo-political tensions).

The supply chain guidance or requirements may not apply to upstream supply chain companies, but they could have an 'upstream cascading' effect, making (some of) the main suppliers to critical chains to also better manage supply chain risks, including those based outside of the EU.

The recommended policy measures should have a neutral impact on EU competitiveness, unless the mitigation measures adopted by relevant EU entities ensure their continuous operation under future disruptions from certain hazards (such as pandemics) so extensive and persistent that otherwise businesses financial security and ability to honour contracts would be severely compromised.

The recommended policy measures would have a positive cost-benefit ratio given the benefits to increase supply chain resilience and the low additional costs given entities will already be required to develop risk mitigation measures under the CER and the NIS 2 Directives proposals.

Best practices

The European Network and Information Security Agency has created the "Guidelines for Enhancing the Resilience of Communication Networks"[327]. While not focused on supply chains, it aims to be a tool for staff at communication network operators to understand resilience and its challenges, also providing a structured list of potential measures to increase the resilience of communication networks.

[327] European Network and Information Security Agency. (2009). Guidelines for Enhancing the Resilience of Communication Networks – Provider's Measures. Available at: https://joinup.ec.europa.eu/sites/default/files/document/2014-12/Guidelines%20for%20Enhancing%20the%20Resilience%20of%20Communication%20Networks%20-%20Providers%20Measures.pdf

Table 3-7 Summary table for recommendation 5

Summary – 5. Improve risk assessment and management by relevant entities	
Measure description	
Description	The objective of this measure is to improve risk assessment and management by relevant entities based on the following recommendations: 5.1: Provide a guidance for EU energy companies assessing and managing supply chain-related risks. 5.2: Leverage the CER and NIS 2 Directive proposals to ensure relevant entities conduct the risk assessment and implement corresponding measures.
Timeline of implementation	• Short term
Implementation responsibility	• EU level
Nature of policy action	• Voluntary / improvements to EU policy instruments
Existing policy instruments	• Council Directive on protecting Critical Infrastructures and proposal for a Directive on the Resilience of Critical Entities • Directive on the Security of Networks and Information Systems and proposal for its revision • Regulation on Risk-preparedness in the Electricity Sector • Regulation on Security of Gas Supply
Elements of critical supply chains affected	• PV cells and modules (solar PV supply chain) • Cybersecurity of hardware and software / 3rd party services (wind, electricity networks, gas infrastructure supply chains) • Li-ion cells, cathode, anode, electrolyte, separator (batteries supply chain) • Other elements with high concentration of non-EU suppliers or important cyber-security vulnerabilities
Vulnerabilities	• Various vulnerabilities addressed, especially those related to supplier relations or cyber-security vulnerabilities and affecting small and medium enterprises
Vulnerable EU regions / Member States	• Critical supply chains where risk management by entities would be beneficial present in all EU Member States. Certain supply chains more important in specific regions (e.g. wind and solar PV), while others such as electricity networks are relevant to all Member States (especially considering developments to 2050.
Related threats and hazards	• Cyber-attacks • Extreme weather events, persistent pandemics and geo-political tensions
Assessment of the proposed measure	
Impact on the resilience of critical supply chains	• Should increase resilience of supply chains, especially regarding hazards overlooked by actors (extreme weather events and geo-political tensions)
Impact on EU competitiveness	• Neutral impact on EU competitiveness
Cost-benefit ratio	• Positive given benefits to resilience of EU critical energy supply chains and low associated costs
Best practices	
Best practices	• European Network and Information Security Agency "Guidelines for Enhancing the Resilience of Communication Networks" • US Department of Homeland Security "Supply Chain Resilience Guide"

3.2.6. ***Recommendation 6:*** *Continue the analysis of supply chain vulnerable elements in preparatory studies for ecodesign product-specific regulations*

Problem area description

Product-specific ecodesign regulations have or are being developed for products relevant for critical energy technology supply chains, for example power transformers (elements in the wind and electricity networks supply chains), servers and data storage products (part of the digital technologies supply chains and to be found across the energy sector), and the on-going work for ecodesign requirements for building automation and control systems (BACS). Electrical steel, servers and data storage equipment are considered vulnerable due to the high import dependence of the EU coupled with market concentration for those elements, while in the case of BACS the EU is a global leader but the US is in a leading position concerning home energy management software – although this is a fast evolving landscape with many new players.

Ecodesign requirements may also exist for other products employed in critical supply chains but which are not considered vulnerable elements themselves, such as electrical motors (part of several critical electricity technology supply chains such as wind and gas turbines). In these cases, the supply chains are considered critical due to vulnerabilities of other elements that are not affected by ecodesign requirements.

Ecodesign product-specific regulations, which include requirements for environmental performance, energy efficiency & quality of products have a beneficial effect in reducing the lifecycle energy consumption and cost of products. By incentivising innovation, ecodesign requirements can also increase the competitiveness of EU manufacturers in the internal market as well as abroad.

Achieving higher energy efficiency can entail the use of new technology or more efficient materials, reducing total lifecycle material and energy use. But demand for specific high-efficiency material and product sub-groups may increase, as this may be a way for industry to meet the requirements (e.g. by using higher permeability electrical steel). While having positive effects on lifecycle costs and energy consumption as well as potentially on competitiveness of the EU industry for a certain product, ecodesign and other requirements can increase the dependence of the industry on non-EU suppliers, in case the EU manufacturers cannot meet the increased demand for certain higher-efficiency manufacturing inputs (even if total material or product demand decreases). The present recommendation aims to provide knowledge on the latter effect within the ecodesign framework, so that any negative impacts can be mitigated by other policy measures.

Existing policy instruments

The **Ecodesign Directive**[328] establishes a process for developing EU rules for improving the environmental performance of products, establishing minimum mandatory requirements for their energy efficiency. The Ecodesign Working Plans program the development of product-specific regulations, while the **Methodology for Ecodesign of Energy-related Products** (MEErP) is employed to conduct the preparatory studies for product specific regulations.[329] The MEErP explicitly indicates the studies should cover the EU manufacturing, extra- and intra-EU trade, and consumption of the product.

As part of the EU Green Deal and the Circular Economy Action Plan, in 2020 the European Commission launched a consultation for an inception impact assessment on a **Sustainable Products Initiative**.[330] It indicates the Ecodesign Directive should be broadened beyond energy-related products as well as introduce sustainability-related principles. As of April 2021, the Commission was working towards the legislative proposal to revise the Ecodesign Directive and the accompanying impact assessment.

In 2020 the Commission also published the **Chemicals Strategy for Sustainability,**[331] where one of the stated objectives is to "promote the EU's resilience of supply and sustainability of chemicals used in essential applications for society". Therefore actions related to the strategy could help address potential vulnerable chemicals employed in critical energy technology supply chains. Although chemicals were not in general identified as vulnerable components, more resilient supply of chemicals such as polyethylene for electricity networks and electrolytes for hydrogen fuel cell would be welcome.

A number of other EU policy instruments relate to sustainable products, including the EU ecolabels and energy labels, the Non-financial Reporting Directive 2014/95/EU, and the EU Eco-Management and Audit Scheme. While not focusing on supply chain-resilience aspects, by advancing the lifecycle assessment of energy-using and other products, such measures can indirectly increase the understanding of energy technology supply chains.

Policy gap

Trade impacts for the main products and frequently input components are analysed in the preparatory studies to different extents. For example, the 2011 preparatory study for power transformers provided a detailed overview of the EU and global market and manufacturers for electrical steel (including high-permeability), and the 2017 preparatory study (for the amending regulation) overviewed price developments since then (with lower attention to EU supply sources for high-permeability electrical steel). It must be noted that the assessment of manufacturing and trade

[328] Directive 2009/125/EC Establishing a Framework for the Setting of Ecodesign Requirements for Energy-related Products
[329] DG GROW - Sustainable product policy & ecodesign
[330] European Commission. (2020). Inception Impact Assessment on Sustainable Products Initiative. Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12567-Sustainable-products-initiative_en
[331] European Commission. (2020). SWD(2020) 667 final. Chemicals Strategy for Sustainability. Towards a Toxic-Free Environment. Available at: https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf

impacts of ecodesign requirements is also dependent on information provided by industry and their associations, which may be constrained by data confidentiality.

An ecodesign product-specific regulation impact assessment focuses on the most important technical, economic and environmental impacts. Hence, depending on whether the ecodesign requirements are assessed to have an important impact on manufacturing and trade of the product or any of its components, the preparatory study findings may be taken up in the impact assessment. The inception impact assessment for the sustainable product initiative specifically acknowledges there is a 'lack of reliable information on sustainability along value chains related to many products placed on the EU market'.[332]

Necessity and EU added value to act

There is a well established basis for product ecodesign action at the EU level as well as demonstrated benefits. As the recommendation is about the maintenance of existing practices regarding the work for developing product-specific ecodesign regulations, there is no need to further argue for the necessity of the EU to act. Nonetheless, there is significant benefits to critical energy technology supply chains from the EU continuing to pay attention to manufacturing and trade impacts in the preparation of ecodesign requirements. Moreover, this has synergies with the recommendation on the monitoring of critical supply chains and that concerning circular economy measures, as such ecodesign preparatory work increases the knowledge of the critical supply chains. The important link between ecodesign actions and critical supply chains is demonstrated by the number of critical supply chains of the present studies which are related to existing or upcoming product-specific regulations (as mentioned, for power transformers, servers and data storage equipment, and building automation and control systems).

Objective and description of recommended policy measure

Recommendation 6.1: Maintain and enhance, where necessary, the detailed analysis in the preparatory studies of impacts of ecodesign requirements on the product and vulnerable elements of the supply chain. If the ecodesign requirements are found to have significant impacts (positive or negative) regarding demand for vulnerable components, their production in the EU and trade (especially with non-EU partners), they should be taken up in the Commission Impact Assessment, as is currently the case. If any important negative impacts are forecasted, they can be mitigated through other appropriate EU instruments such as support to R&I and EU-based manufacturing.

Impact of recommended policy measure

Systematically considering trade impacts on the supply chain when assessing product-specific ecodesign requirements helps to identify vulnerable elements in the product supply chain, provide transparency on import dependencies and assess likely impacts on trade of these elements. Positive impacts on the competitiveness of the EU industry and EU trade balance will support the implementation of the ecodesign requirements, while any negative impacts identified can possibly be addressed by industrial policy measures.

The measure could have positive impacts on the competitiveness of the EU critical energy technology supply chains by allowing to mitigate potential negative trade impacts with industrial policy measures. Impacts on energy technology supply chains without vulnerable elements would be neutral. Administrative costs are limited or inexistent, as the analysis of supply chain trade impacts is already often done and is a small cost compared to the overall ecodesign product-specific regulations impact assessments and preparatory studies. The cost-benefit ratio would be positive (for product supply chains with vulnerable elements) to neutral (for product supply chains without vulnerable elements).

The impact of measures on certain EU regions / Member States will depend on the exact energy-using product and related critical supply chain. For example, transformers employed in electricity networks related to all MSs, while transformers employed in wind turbines and farms affect MSs with strong current or future wind deployment – e.g. DE, ES, FR, IT regarding absolute wind power deployment, and DK, IE or LT regarding the relative share of total electricity supply.

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[332] European Commission. (2020). Inception Impact Assessment on Sustainable Products Initiative. Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12567-Sustainable-products-initiative_en

Table 3-8 Summary table for recommendation 6

Summary – 6. Continue the analysis of supply chain vulnerable elements in preparatory studies for ecodesign product-specific regulations	
Measure description	
Summary	The objective of this measure is to ensure preparatory studies for ecodesign product-specific regulations continue to identify and, if relevant, consider supply chain vulnerabilities, based on the following recommendations: 6.1: Maintain and enhance, where necessary, the detailed analysis in the preparatory studies of impacts of ecodesign requirements on the product and vulnerable elements of the supply chain. If the ecodesign requirements are found to have significant impacts (positive or negative) in the vulnerable components regarding EU manufacturing and (especially extra-EU) trade, they should be taken up in the Commission Impact Assessment, as is currently the case.
Timeline of implementation	• Short-term (refers to maintenance of existing practices)
Implementation responsibility	• EU level
Nature of policy action	• Maintaining existing policy instruments
Existing policy instruments affected	• Directive 2009/125/EC establishing a framework for the setting of ecodesign requirements for energy-related products • Sustainable Product Initiative • Chemicals Strategy for Sustainability-related instruments
Elements of critical supply chains affected	• Electrical steel (wind and electricity networks supply chains) – Product-specific regulation exists already • Servers and data storage (digital technologies supply chain) – Product-specific regulation exists already • Smart buildings (Building Automation and Control Systems) – work on-going for regulation proposal, but BACS themselves are not found to be vulnerable
Vulnerabilities	• Import dependence combined with supplier concentration are the relevant vulnerabilities
Vulnerable EU regions / Member States	• Specific vulnerable EU regions / Member States will depend on the exact energy-using product and related critical supply chain.
Related threats and hazards	• Persistent pandemics, extreme weather events and geo-political tensions can all impact the supply of components by foreign suppliers concentrated in specific regions
Assessment of the proposed measure	
Impact on the resilience of critical supply chains	• Helps identify vulnerable elements in the product supply chain, provide transparency on import dependencies and assess likely impacts on trade of these elements.
Impact on EU competitiveness	• The measure has positive impacts on the competitiveness of the EU critical energy technology supply chains. Impacts on energy technology supply chains without vulnerable elements would be neutral.
Cost-benefit ratio	• Administrative costs are limited or inexistent. • The cost-benefit ratio would be positive (for product supply chains with vulnerable elements) to neutral (for product supply chains without vulnerable elements).
Best practices	
Best practices	• The analysis on production and demand for high-permeability electrical steel in the preparatory studies for power transformers ecodesign regulations.

3.2.7. Recommendation 7: Further integrate circular economy measures (recycling & substitution)

Problem area description

This recommendation addresses the limited recycling of critical materials and need to further implement other circular economy principles, such as material substitution and resource efficiency, to decrease the EU external dependence for certain critical raw materials while also decreasing the use of natural resources (land, water, fuel, etc.) and the emission of polluting substances over the whole technology life cycle (extraction, transport, processing, use and end of life). Recycling is essential also to anticipate potential resource depletion issues, particularly for fast-growing technologies (such as batteries, EVs, hydrogen, smart buildings and digital technologies).

Several raw materials used in the energy supply chains, such as aluminium, copper or platinum are highly recyclable due to their intrinsic characteristics, their durability in use, or to the very high recovery rates that could be achieved once the material-containing end-of-life product reaches a recycling factory. Therefore, the potential for effective recycling is generally high.

The main barrier to the recycling of these materials lies in ensuring that end-of-life products are collected and enter an appropriate recycling chain. The collection and recycling rates of end-of-life products varies considerably by material, by product and by application. Therefore, possibilities to save resources and to substitute rare materials are available, but are far from being fully exploited, and - particularly with regard to material efficiency - are often not very well-known.[333] Increasing the recycling rate of the critical raw materials will contribute to increase the energy supply chains resilience.

Businesses already implement a diverse range of resource efficient practices. Constantly increasing productivity is an inherent part of all businesses. The reduction of material consumption often implies cost savings and therefore a common activity in companies. However, as some studies[334,335] show, there is still some room for improvement.

Although recycling / circularity is crucial to increase the resilience of EU economy and to improve its environmental impact, it must be noted that the supply of primary materials is still required, and will certainly remain so until there is enough material within the economy, ideally within EU, and recycling rates are hight enough to rely only on secondary materials. This highlights again the importance for all other actions like substitution or import diversification, and for bringing recycling as a mean to increase resilience and sustainability, but not as an objective per se, with as consequence that EU should not stop importing before having enough material on its own territory. Short to medium-term actions should keep this in mind.

This becomes even more important when the demand for some materials, like CRMs, faces a steep increase, as these may take time before they enter the recycling phase (considering the life time of products, such as for the PV industry which already has recycling expertise but is expected to put this expertise into practice on a large scale only in the coming years when more solar PV plants are expected to be decommissioned due to the end of their lifetime) Recycling will increase, but at least in the short-term, it is necessary to ensure there is sufficient supply to meet this increase in CRM demand.

Existing policy instruments

The European Green Deal's **Circular Economy Action Plan**[336] supports the EU economy to supply an increasing share of the EU's raw materials demand with secondary materials (e.g. in EU more than 50% of some metals such as iron, zinc, or platinum are recycled and they cover more than 25% of the EU's consumption). The sustainability challenge posed by key value chains requires urgent, comprehensive and coordinated actions. Some of these actions will contribute to the response to the climate emergency and will feed into the EU Industrial Strategy[337]. In the frame of the CEAP actions, the Commission will, among others:

- **cooperate closely with stakeholders in key value chains to identify barriers to the expansion of markets for circular products** and ways to address those barriers. Among those chains, the most relevant are: Electronics and ICT (covering smart buildings and digital technologies, but also part of electricity networks); batteries and vehicles (covering battery and possibly fuel cells for mobile applications);
- **propose a sustainable product policy legislative initiative**. EU initiatives and legislation already address to a certain extent sustainability aspects of products, either on a mandatory or voluntary basis, such as the Ecodesign Directive, regulating energy efficiency and some circularity features of energy-related products. The methodology for the ecodesign of energy-related products (MEErP) has been established to support the preparatory studies for

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[333] BIO Intelligence Service et. al. (2013). Material-efficiency Ecodesign Report and Module to the Methodology for the Ecodesign of Energy-related Products (MEErP) - PART 1:MATERIAL EFFICIENCY FOR ECODESIGN. Available at https://op.europa.eu/en/publication-detail/-/publication/7c3d958d-42cc-4af7-985c-2a3347b66fa8

[334] Hollins, O. (2011). The further benefits of business resource efficiency. A research report completed for the Department of Environment, Food and Rural Affairs. Available at: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=2&ProjectID=16943

[335] Urban Mines for BIS. (2010). Potential for resource efficiency savings for businesses. Available at: http://www.enworksinabox.com/sites/default/files/BIS%20Potential%20for%20Resource%20Efficiency%20Savings%20Report%202009.pdf

[336] European Commission. (2020). COM(2020) 98 final. A new Circular Economy Action Plan for a cleaner and more competitive Europe. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0098

[337] European Commission. (n.d.). .European industrial strategy. Available at: https://ec.europa.eu/growth/industry/policy_en

designing product-specific ecodesign measures.[338] In that frame the **Material-efficiency Ecodesign Report and Module to the MEErP** aims to extend the MEErP by including further the consideration of material efficiency.[339] Several existing legislations include to a certain extent material related measures, such as the Waste Framework Directive (2008/98/EC), the Waste of Electric and Electronic Equipment Directive (2012/19/EU), the Restriction on Hazardous Substances Directive (2011/65/EU), the End-of-Life Vehicles Directive (2000/53/EC), or the Directive on Batteries and accumulators and waste batteries and accumulators (2006/66/EC);

- enable **greater circularity in industry** by assessing options for further promoting circularity in industrial processes in the context of the review of the Industrial Emissions Directive, including the integration of circular economy practices in upcoming Best Available Techniques reference documents; facilitating industrial symbiosis by developing an industry-led reporting and certification system, and enabling the implementation of industrial symbiosis; promoting the uptake of green technologies through a system of solid verification by registering the EU Environmental Technology Verification scheme as an EU certification mark;
- has proposed a **new regulatory framework for batteries**[340,341] and will propose to revise the rules **on end-of-life vehicles** with a view to promoting more circular business models by linking design issues to end-of-life treatment, considering rules on mandatory recycled content for certain materials of components, and improving recycling efficiency;
- propose a **Global Circular Economy Alliance** to identify knowledge and governance gaps in advancing a global circular economy and take forward partnership initiatives, including with major economies;
- ensure that **Free Trade Agreements** reflect the enhanced objectives of the circular economy.

Policy gap

The European Green Deal's **Circular Economy Action Plan** (CEAP, COM(2020) 98 final[342]) partially covers smart buildings and digital technologies, electricity networks, batteries and vehicles, including some components of fuel cells. PV panels and inverters are already considered in ongoing ecodesign preparatory study[343,344]. The ecodesign regulation on electric motors[345] addresses wind turbines generators, and the one on power transformers partially addresses electricity networks. A preparatory study on buildings automation and control systems is also on-going.[346] The following critical supply chains identified in this study are not covered: gas infrastructure, hydrogen electrolysers and stationary fuel cells.

The Action Plan, via policy and legislation (such as REACH), encourages a shift to 'safe-by-design chemicals' through the progressive substitution of hazardous substances. It recalls Horizon Europe

[338] The methodology has been established in 2011. See COWI and VHK for the European Commission (2011). Methodology for Ecodesign of Energy-related Products. MEErP 2011 Methodology Report – Part 1: Methods. Available at: https://ec.europa.eu/docsroom/documents/26525

[339] BIO Intelligence Service et al. (2013) Material-efficiency Ecodesign Report and Module to the Methodology for the Ecodesign of Energy-related Products (MEErP) - PART 1:MATERIAL EFFICIENCY FOR ECODESIGN. Available at https://op.europa.eu/en/publication-detail/-/publication/7c3d958d-42cc-4af7-985c-2a3347b66fa8

[340] European Parliament. (February 2021). Briefing: New EU regulatory framework for batteries - Setting sustainability requirements. Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689337/EPRS_BRI(2021)689337_EN.pdf

[341] European Commission. (2020). COM(2020) 798 final. Proposal for a Regulation of the European Parliament and of the Council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020PC0798

[342] European Commission. (2020). COM(2020) 98 final. A new Circular Economy Action Plan for a cleaner and more competitive Europe. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0098

[343]Nicholas, D., and Nieves, E. (2019). . Preparatory study for solar photovoltaic modules, inverters and systems – Task 8 Policy recommendations, European Commission, Joint Research Centre. Available at: https://susproc.jrc.ec.europa.eu/product-bureau//sites/default/files/contentype/product_group_documents/1581689975/20191220%20Solar%20PV%20Preparatory%20Study_Task%208_Final%20version.pdf

[344] REGLOBAL. (2021). Eco-design and energy labelling for solar PV in the EU. Available at: https://reglobal.co/eco-design-and-energy-labelling-for-solar-pv-in-the-eu/

[345] European Commission. (n.d.). Ecodesign- Electric motors. Available at: https://ec.europa.eu/growth/single-market/european-standards/harmonised-standards/ecodesign/electric_motors_en

[346] European Commission (n.d.) Ecodesign preparatory study for Building Automation and Control Systems. Available at: https://ec.europa.eu/energy/studies_main/preparatory-studies/ecodesign-preparatory-study-building-automation-and-control-systems_en

will support the substitution of the same hazardous substances. It does not consider substitution of critical material for other reasons than their hazardous characteristics.

The **Material-efficiency Ecodesign Report and Module to the Methodology for the Ecodesign of Energy-related Products (MEErP)** study presents a list of key material efficiency aspects covering the entire life cycle of Energy related Products (ErP). However, the study was carried out in 2013, and is currently being updated[347]. Ecodesign product-specific regulations were developed in 2015 or after for the following products relevant for critical supply chains: power transformers (wind and electricity networks supply chains) and servers and data storage equipment (digital technologies supply chains). In addition, the building automation and control systems (BACS) ecodesign requirements are being prepared. Figure 3-4 presents the list of priority materials for ecodesign which should be covered in the preparatory studies, according to the material efficiency methodology. The comparison of this list with the identified list of critical raw materials of the present study indicates that some materials are missing, such as boron, germanium, platinum.

Figure 3-4 Preliminary list of priority materials for ecodesign[348]

Proposed priority materials for ecodesign purposes	
Metals	Aluminium
	Beryllium
	Chromium
	Cobalt
	Copper
	Gallium
	Gold
	Indium
	Iron
	Magnesium
	Nickel
	Niobium
	Silicium
	Tantalum
	Tungsten
	Zinc
Platinum group metals	Palladium
	Rhodium
Rare Earths Metals	Dysprosium
Non-metallic minerals	Antimony
	Fluorspar
	Graphite
	Germanium
Processed materials	Polyethylene (PE)
	Polypropylene (PP)
	Polyethylene terephtalate (PET)
	Glass
Bio materials	Wood
	Paper and cardboard

Necessity and EU added value to act

Action at the EU level concerning circular economy measures to increase the resilience of critical supply chains is justified by the highly integrated nature of the circular economy actions, the cross-border nature of material and product flows, and the common challenges concerning products design, end-of-life product collection and treatment, and recycling of materials.

[347] European Commission. (n.d.). MEErP revision. Available at: https://susproc.jrc.ec.europa.eu/product-bureau/product-groups/521/home

[348] Source from Table 3 of BIO Intelligence Service (2013), Material-efficiency Ecodesign Report and Module to the Methodology for the Ecodesign of Energy-related Products (MEErP), Part 1: Material Efficiency for Ecodesign – Draft Final Report. Prepared for:European Commission - DG Enterprise and Industry, p. 33. Available at: https://op.europa.eu/en/publication-detail/-/publication/7c3d958d-42cc-4af7-985c-2a3347b66fa8

The same logic applies for the **Methodology for the Ecodesign of Energy-related Products (MEErP)**. Any measure related to the Ecodesign should be addressed at EU level for the aim of global efficiency. As the basis for EU action developing product-specific ecodesign regulations, there is no need to further argue for the necessity of the EU to act.

Objective and description of recommended policy measure

Recommendation 7.1: when conducting all CEAP actions (including when developing a sustainable product policy legislative initiative), it is recommended to identify **further product groups** based on their environmental impact, and their circularity potential, while considering their contribution to the clean energy transition.
As first initiative among the actions announced in the new Circular Economy Action Plan (announced on 10 December 2020[349]), the European Commission proposed to modernise EU legislation on batteries. Batteries that are more sustainable throughout their life cycle are key for the goals of the European Green Deal[350] and contribute to the zero pollution ambition set in it. The proposal addresses the social, economic and environmental issues related to all types of batteries.

Batteries placed on the EU market should become sustainable, high-performing and safe all along their entire life cycle. With the Batteries Regulation proposal, the Commission proposes mandatory requirements for all batteries (incl. electric vehicle) placed on the EU market. Requirements such as use of responsibly sourced materials with restricted use of hazardous substances, minimum content of recycled materials, carbon footprint, performance and durability and labelling, as well as meeting collection and recycling targets, are essential for the development of more sustainable and competitive battery industry across Europe and around the world.

Recommendation 7.2: when carrying out the next update of the **Methodology for the Ecodesign of Energy-related Products (MEErP)** study, further explore extending the scope to new materials that are relevant for the purpose of the critical energy supply chains, and consider substitution (in the frame of RD&I) not only to replace hazardous substances, but also to replace substances with important supply chain risks. The same extension should be considered for the upcoming Sustainable Product Initiative.

Impact of recommended policy measure

The inclusion of new products groups in the Circular Economy Action Plan, and the Ecodesign working plans would help accelerate the recycling of critical materials at EU scale, to decrease the EU economic players' dependency, strengthen the related supply chains, and increase global EU competitiveness. To remain proportionate, this inclusion should be based on the groups with materials that are critical and have a high level of recyclability.

The recommended measure could lead to additional administrative costs to address additional product groups and their related materials, such as fuel cells, or electrolysers. It could therefore have an administrative negative effect, which magnitude would depend on the complexity to set up the whole recycling system (design, production, end-of-life products collection, use of recycled materials). Globally, the recommended measure would have a positive cost-benefit ratio given the benefits on EU competitiveness, compared to the additional administrative costs.

[349] European Commission. (December 10, 2020). Green Deal: Sustainable batteries for a circular and climate neutral economy. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2312
[350] European Commission. (2021). A European Green Deal: Striving to be the first climate-neutral continent. Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

Table 3-9 Summary table for recommendation 7

Summary – 7. Further integrate circular economy measures (recycling & substitution)	
Measure description	
Description	The objective of this measure is to further mainstream the circular economy and the clean energy transition based on the following recommendations: Recommendation 7.1: when conducting all CEAP actions (including when developing a sustainable product policy legislative initiative), it is recommended to identify **further product groups** based on their environmental impact, and their circularity potential, while considering their contribution to the clean energy transition Recommendation 7.2: when carrying out the next update of the **Methodology for the Ecodesign of Energy-related Products (MEErP)** study, further explore extending the scope to new materials that are relevant for the purpose of the critical energy supply chains, and consider substitution (in the frame of RD&I) not only to replace hazardous substances, but also to replace substances with important supply chain risks. The same extension should be considered for the upcoming Sustainable Product Initiative.
Timeline of implementation	• Short-term (refers to maintenance of existing practices)
Implementation responsibility	• EU level
Nature of policy action	• Maintaining existing policy instruments
Existing policy instruments affected	• The European Green Deal's Circular Economy Action Plan (CEAP, COM(2020) 98 final[351]) related instruments • material-efficiency aspects of the Methodology for the Ecodesign of Energy-related Products (MEErP)
Elements of critical supply chains affected	• raw materials (focusing on the most recyclable) • possibly some processed materials
Vulnerabilities	• Import dependence combined with supplier concentration are the relevant vulnerabilities
Vulnerable EU regions / Member States	• Still EU, but this will evolve with the implementation of the CEAP
Related threats and hazards	• Persistent pandemics, extreme weather events and geo-political tensions can all impact the supply of components by foreign suppliers concentrated in specific regions
Assessment of the proposed measure	
Impact on the resilience of critical supply chains	• Helps decrease dependency on imports in the product supply chain, recycling and replacing the vulnerable elements.
Impact on EU competitiveness	• The measure has positive impacts on the competitiveness of the EU critical energy technology supply chains and supports the deployment of circular economy activities.
Cost-benefit ratio	• Administrative costs are limited or inexistent. • The cost-benefit ratio would be positive (for product supply chains with vulnerable elements) to neutral (for product supply chains without vulnerable elements).

[351] European Commission. (2020). COM(2020) 98 final. A new Circular Economy Action Plan for a cleaner and more competitive Europe. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0098

4. ANNEX A: STUDY METHODOLOGY

The scope of the study is as follows:

- **The main focus of the study is on the EU27.** The supply chains criticality are assessed from the EU perspective, with additional attention being paid to supply chains which could be particularly relevant to some EU regions and/or Member States. However, the EU remains the main focus;
- **Energy technology supply chains are analysed.** Energy commodity supply chains are not within the scope (e.g. natural gas or uranium supply chains), unless relevant for the technology supply chains;
- **The supply chains assessment considers international links** with non-EU economies. But if there are no or limited external dependencies nor internal vulnerabilities, the technology supply chain are not considered critical;
- **The final time horizon of the study is 2050**. Technologies only relevant beyond this point such as nuclear fusion are out of scope;
- **Policy options are developed focusing on the EU level,** potentially with cooperation of the European Commission with Member States and economic operators.

4.1. Identification of the critical supply chains for the energy sector

Chapter 1 identifies the critical supply chains to ensure the EU's security of energy supply and clean energy transition taking into account the equipment, components, materials and services needed to develop, maintain and operate energy supply, transport, storage and end-use projects, equipment and appliances.

4.1.1. Concepts definition and methodology

Definition of critical supply chains and other concepts

This study focuses on energy technology supply chains, defined here as *the combination of all the elements (raw and processed materials/(sub-)components/equipment/services or skills) necessary for a specific energy technology.*

Energy technology supply chains can comprise different levels of aggregation. For example, an electric vehicle (EV) is an energy technology, employing in most cases a lithium-ion battery. The lithium-ion battery supply chain can be analysed on its own or as a sub-supply chain of EVs. Similarly for other energy technologies and their main sub-components. Particularly broad energy technologies, such as electricity networks, could lead to highly-aggregated supply chains, some of which would constitute supply chains in their own right, such as AC/DC converters.

The first step in the identification of critical supply chains was to **agree on a definition of what constitutes a critical supply chain.** Studies such as the DG RTD Energy Technology Dependence[352] or the European Commission assessment of Critical Raw Materials[353] combine two necessary conditions for criticality:

- **Importance to the EU,** such as to attain the EU targets for GHG emission reduction, energy efficiency or renewable energy, security of energy supply or the relevance of the specific material/technology/supply chain to the EU economy;
- **Risks to the EU regarding tangible and intangible elements of the supply chains (material/technology/skills/services)**, such as high dependency on international suppliers.

As such, as depicted in Figure 4-1 below, we defined critical supply chains for the energy sector as those with a:

- **Strategic importance to the EU** clean energy transition and/or to guarantee the security of energy supply; and a
- **High vulnerability**, regarding the entire supply chain, or specific stages (construction & installation, decommissioning) or elements (e.g. raw & processed materials, or a certain expertise for O&M, a sub-components).

[352] Trinomics et. al. for European Commission - DG RTD. (2017). Study on energy technology dependence. Available at: https://op.europa.eu/en/publication-detail/-/publication/344b4c68-538f-11ea-aece-01aa75ed71a1
[353] European Commission. (2020). COM(2020) 474 final. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0474

Figure 4-1 Necessary conditions for supply chain criticality

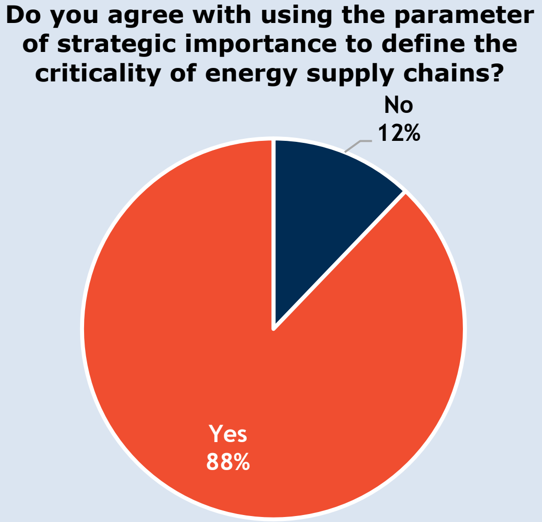
An online survey ran from September to October 2020 in order to collect inputs from stakeholders on the project methodology as well as the strategic importance and vulnerability of the energy technology supply chains. The survey respondents largely agreed with the use of strategic importance and vulnerability as the main conditions to identify critical supply chains (see Textbox 4-1).

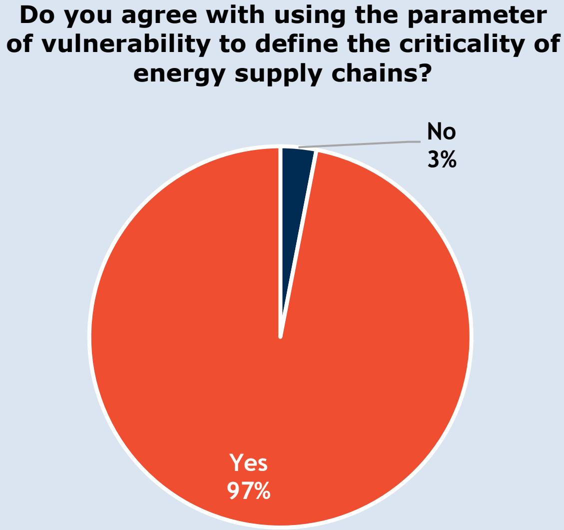
Textbox 4-1 Opinions of survey respondents' on using strategic importance and vulnerability to determine critical supply chain criteria

The majority of the survey respondents (88%) agreed with using the parameter of strategic importance to define the criticality of energy supply chains. Comments received for disagreeing with the use of strategic importance as a parameter includes the lack of clarity of how 'strategic' is being defined (which is further defined in this section), and also the suggestion to make a distinction between the strategic importance for security of supply, and for the clean energy transition (which can be derived from the indicators for strategic importance). A respondent also commented that the criticality criteria could consider the importance to the EU economy.

A large majority (97%) of the respondents agreed with using the parameter of vulnerability to define the criticality of energy supply chains. One respondent mentioned that this vulnerability assessment should also consider the underlying reasons for import dependence, for example lack of competitiveness of the EU industry, or other national / trade / economic interests (this is considered in the vulnerability analysis for each supply chain). A respondent also suggested considering the likelihood of each vulnerability leading to a supply chain disruption (this is considered in the transversal analysis of vulnerabilities).

Figure 4-2 Survey answers to using strategic importance and vulnerability to determine the critical supply chains ($n_{respondents}$ = 33)





In section 1.1 we identified the most strategic supply chains and in section 1.2 we assessed the vulnerabilities of these supply chains. Both assessments were closely interrelated in an iterative process to ensure supply chain elements with a marginal importance for one supply chain, but being highly relevant for several other supply chain technologies, could be considered as important. The final identification of the critical supply chains was an iterative process and presented as an outcome of chapter 1.

This approach on the importance and the risk (vulnerability) is aligned with the EU Commission communication on Critical Raw Materials Resilience[354] defining critical raw materials as:

> "*Economic importance and supply risk are the two main parameters used to determine criticality for the EU.* ***Economic importance*** *looks in detail at the allocation of raw materials to end-uses based on Industrial applications.* ***Supply risk*** *looks at the country-level concentration of global production of primary raw materials and sourcing to the EU, the governance of supplier countries, including environmental aspects, the contribution of recycling (i.e. secondary raw materials), substitution, EU import reliance and trade restrictions in third countries.*"

In addition to strategic importance, a number of concepts were defined and applied consistently throughout the study. These are summarised in Table 4-1.

Table 4-1 Summary of concepts for the purpose of this study

Concept	Definition
Energy technology supply chain	The combination of all the elements (raw and processed materials/(sub-) components/equipment/services or skills) necessary for a specific energy technology.
Critical supply chain	A supply chain - Considered of strategic importance for the EU; and - With high vulnerability for specific supply chain elements.
Strategic importance	Importance to ensure security of energy supply (now and/or in 2050) and/or to the EU to attain its 2050 GHG emission reduction targets
Vulnerability	Level of sensitivity/exposure to external disruptions to the supply chain
Supply chain element	A raw and processed material, equipment, (sub-)component, services or skills employed in a supply chain
Supply chain stage	One of the steps of the supply chain: raw & processed materials production, manufacturing, transport, construction & installation, operation & maintenance or decommissioning & circularity

4.1.2. Identification of strategic supply chains

Criteria and indicators to select strategic supply chains

Starting with a long list of pre-identified supply chains, the strategic importance of these was analysed. Once the strategic supply chains were selected, we assessed the vulnerability of these chains or of their elements. This section describes the methodology to identify the strategic supply chains.

Table 4-2 presents the indicators to assess the importance of energy technologies to the EU security of energy supply (in the short- and long-term) and the clean energy transition (in the long-term). The indicators 1 and 2 are quantitative, while indicators 3 and 4 are qualitative:

- Indicator 1. Current share of energy supply / transport / storage / consumption
- Indicator 2. Long-term share of energy supply / transport / storage / consumption
- Indicator 3. Flexibility provision
- Indicator 4. Policy priorities / other contributions not overviewed

[354] European Commission. (2020). COM(2020) 474 final. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0474

Table 4-2 Indicators to identify strategic supply chains

Horizon	Indicator		Definition	Main source
Short-term	Security of Supply (SoS)	1. Current share of energy supply / transport / storage / consumption	% of energy supply/transport/ storage/demand to final energy consumption	Eurostat, LTS[355]
Long-term	Clean energy transition	2. Long-term share of energy supply / transport / storage / consumption		LTS
	SoS / Clean energy transition	3. Flexibility provision	Provision of flexibility in seasonal/daily timeframes or peak scarcity hours	Energy storage study[356]
Short-term/Long-term		4. Qualitative assessment, based on policy priorities / other contributions not overviewed	Ad hoc assessment	Various

The indicators 1 and 2 are calculated per energy system function performed (supply, transport, storage, sectoral consumption). Calculations on the contributions of the supply chains in indicators 1 and 2 are made relative to the final energy consumption (i.e. final energy consumption was the denominator for calculating the percentages when possible) for all categories except end-use sectors, as it is the final energy which is available to the end users which is the most relevant for consideration in the context of this study. This allows the comparison of the percentages for the energy supply, transport and storage categories. The sectoral energy consumption is used in case of transport and total energy savings in case of building supply chains increasing energy efficiency (e.g. insulation/building envelope or smart buildings technologies).

Indicator 3 is a qualitative indicator reflecting the significant provision of flexibility by a supply chain in either the seasonal or daily timeframes, or during peak scarcity hours (the 100 hours where the residual demand[357] is the highest). The main source are the simulations done for the "Study on energy storage – Contribution to the security of the electricity supply in Europe" study for DG ENER[358].

Indicator 4 is an additional indicator to consider policy priorities and other contributions not covered by indicators 1 to 3. It reflects the iterative process of the definition of strategic supply chains and vulnerability analysis to reflect priorities of the European Agenda (Green Deal, Climate Target Plan,…) that was not captured in the first or second criteria as well as feedback from stakeholders (including Member States). It can be also used to decrease the importance for this assessment of a technology, if there are (policy-related) arguments in favour of not assessing them. It could also have the opposite effect, defining as strategic a supply chain which otherwise would not be considered so according to indicators 1 to 3. Qualitative aspects include:

- **Strategic importance to specific EU regions/Member States;**
- **Limited relevance to long-term policy goals**: coal-based electricity generation, oil production have decreasing relevance on long-term developments;
- **Range of technologies and passive participation**: building shell technologies and efficient appliances/equipment cover a wide range of technologies, have limited repair needs or are passive once installed/built;
- **Efficient use of existing energy infrastructures;**
- **Enabler for other technologies:** e.g. sensoring, metering and control technologies.

The supply chains that are analysed in this study fall in different categories, e.g. in energy supply[359], transport and storage, or demand, which may require different approaches in the analyses. Therefore, although it is generally possible to employ the same indicator and data source within a category[360], as specified in Table 4-2, we refine the specific indicators and data sources for each combination of criteria and supply chain category, where appropriate. Specific assumptions and calculations for each supply chain are presented in Annex C. Once the indicators have been filled in,

[355] European Commission. (2018a). COM/2018/773. A clean planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy.

[356] Trinomics, Artelys and Enerdata. (2020). Study on energy storage – Contribution to the security of the electricity supply in Europe. Available at: https://op.europa.eu/en/publication-detail/-/publication/a6eba083-932e-11ea-aac4-01aa75ed71a1

[357] Residual demand is the total demand minus the supply from intermittent renewable energy sources.

[358] Trinomics, Artelys and Enerdata. (2020). Study on energy storage – Contribution to the security of the electricity supply in Europe. Available at: https://op.europa.eu/en/publication-detail/-/publication/a6eba083-932e-11ea-aac4-01aa75ed71a1

[359] Energy conversion technology supply chains, such as power-to-gas, are addressed in energy supply.

[360] For example, wind and solar PV contributions to the clean energy transition can be assessed according to the same indicators, which can be extracted from the Long-Term Strategy dataset).

the strategic importance thresholds within each category can be defined in order to select the most strategic supply chains.

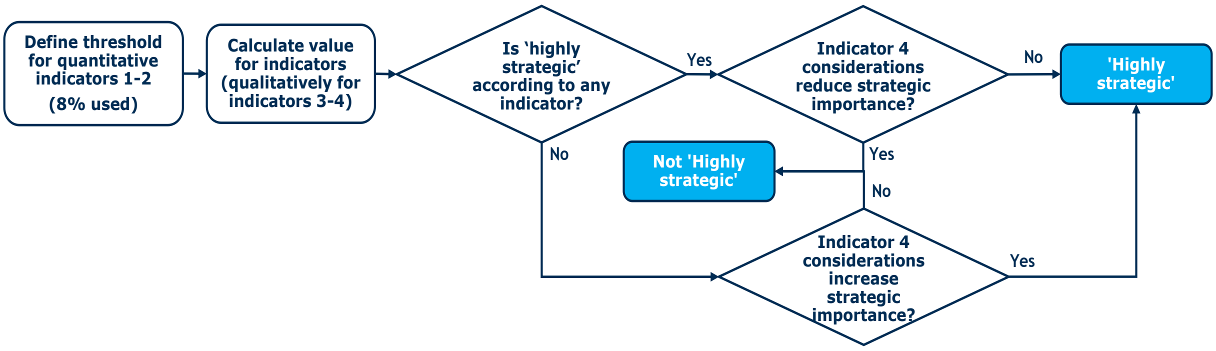
Thresholds are set for classifying the energy technology as "of limited importance" / "important" / "very important" for the indicators 1 and 2, with the threshold value being set to short-list a sensible number of supply chains as highly strategic. Each supply chain the indicators 1 & 2 are rated as 'very important' if the value is equal or above the 8% threshold. That is, if it indicates a share of at least 8% for the energy system function (indicators 1 or 2). The range to rate the indicator as 'important' is 4-8%. While indicator 3 is qualitative, a similar threshold can be used to identify whether the individual supply chains provide flexibility in seasonal/daily timeframes or peak scarcity hours (which is then converted to the qualitative indicator 3). Indicator 4 employs an ad hoc qualitative assessment tailored to each technology supply chain.

The criteria for selection are therefore that an energy technology and its supply chain are considered:

- ***Highly strategic*** if it is *very important* according to any of the indicators, i.e. if the value of any indicator is above 8% for indicators 1-2 or according to indicators 3-4;
- ***Strategic*** if it is *important* according to any indicators, i.e. if the value of any indicator is between 4 and 8% for indicators 1-2 or according to indicator 3-4;
- ***Not strategic*** otherwise.

The process for defining whether a supply chain is highly strategic is illustrated in Figure 4-3.

Figure 4-3 Process for defining 'highly strategic' supply chains according to indicator values and the threshold



The indicators employed for each of the criteria can vary according to the specific source chosen, depending on the model inputs and assumptions (such as the 2050 decarbonisation level in scenarios). The identification of the list of supply chains that are of strategic importance to the EU employed an iterative process with DG Energy and the stakeholders to undergo a qualitative assessment, further to the preliminary assessment based on the set of criteria listed in Table 4-2. This helped to identify any supply chain(s) which may not be identified as one of strategic importance, but may be highly susceptible to specific vulnerabilities.

Justification for the strategic importance indicators

The selected indicators for the strategic importance were largely supported by the survey respondents (Textbox 4-2). The reasoning for the indicator selection is detailed here.

In the context of European **security of energy supply**, a strategic supply chain is understood as an asset or part thereof whose energy services it provides are essential for maintaining a reliable energy system, guaranteeing an uninterrupted energy supply that meets end-user demand across the economy at affordable prices. Threats to these strategic supply chains affecting the European energy security include thus not only disruptions to the supply of energy in Europe but also sharp cost increases to meeting Europe's energy needs. The share of energy services provided by a specific energy technology in the existing or future energy system is therefore a key indicator to ensure the continuous operation of the energy system.

In the context of the European **clean energy transition**, a strategic supply chain is an asset or part thereof whose services it provides constitute a necessary element in achieving net-zero GHG emissions by 2050 in Europe in a cost-effective manner. Threats to these strategic supply chains which affect European clean energy transition comprise, for example, those preventing the achievement of the goal to attain net-zero GHG emissions by 2050; locking the system in a fossil-fuel dependency; or significantly increasing the costs of achieving Europe's clean energy transition.

As all 2050 scenarios (except the baseline) of the LTS already consider a decarbonisation of at least 80% of the EU economy, the technologies which play a central role in the various scenarios already make a central contribution to emission reductions. Hence, to eliminate redundancy of the analysis, a single indicator for assessing the strategic importance of a supply chain to the clean energy transition was employed: the share in energy supply, transport & storage, or consumption in 2050. We used the **1.5TECH** scenario for the analysis as this is the more ambitious scenario which focused on the role of technologies in achieving the 2050 targets.

Flexibility provision will be an important aspect of security of energy supply in the future, as well as for the clean energy transition as system flexibility will facilitate the integration of intermittent renewable energy sources. A common way to divide the flexibility provision to the energy system are the daily, weekly and seasonal timescales.[361] The ability of different energy technologies to provide flexibility varies significantly from one timescales to another, especially from the daily to the seasonal. For this reason, the daily and seasonal flexibility provisions were selected as complementary indicators of long-term security of supply.

There are also **other qualitative aspects** which were important to consider when identifying the strategic importance of a supply chain. This included factors such as the relevance of the energy technology to EU's long-term policy goals, the range of energy technologies available and the passivity of these technology(s)[362], whether the energy supply chains are an efficient use of existing energy infrastructures, and whether they are an enabler for other technologies.

The strategic importance was addressed at EU level. However, some regions (or even Member States) may heavily rely on supply chains that at the EU level were not considered strategic. Therefore, these national/regional supply chains were assessed on an ad-hoc basis. There was no systematic research to identify these national/regional supply chains, but those that are raised by stakeholders were assessed based on the same set of criteria at national (or regional) level. The iterative process did lead to strategic supply chains being identified which are significantly more important to some Member States, particularly nuclear fission and hydro.

Textbox 4-2 Opinions of survey respondents' on the strategic importance indicators

Most respondents (86%) agreed with the use of current and long-term deployment/share as an indicator to measure strategic importance. Relevant comments regarding the use of these indicators included:

- The need for future shares to be in line with EU's decarbonisation ambitions (as is the case as the 1.5TECH scenario of the Long-Term Strategy is employed to calculate them). A respondent indicated even a 100% RES scenario may be preferred;
- The need to use this indicator for specific sectors to identify where an energy carrier may be of particular strategic importance (which is done for the end-use sectors);
- The need to consider regions/areas within the EU which have limited connection with other regions/areas (which is taken in consideration in the iterative approach to determine the strategic supply chains). An example is Ireland, which will be no longer connected directly to the EU gas market after the Brexit transition period.

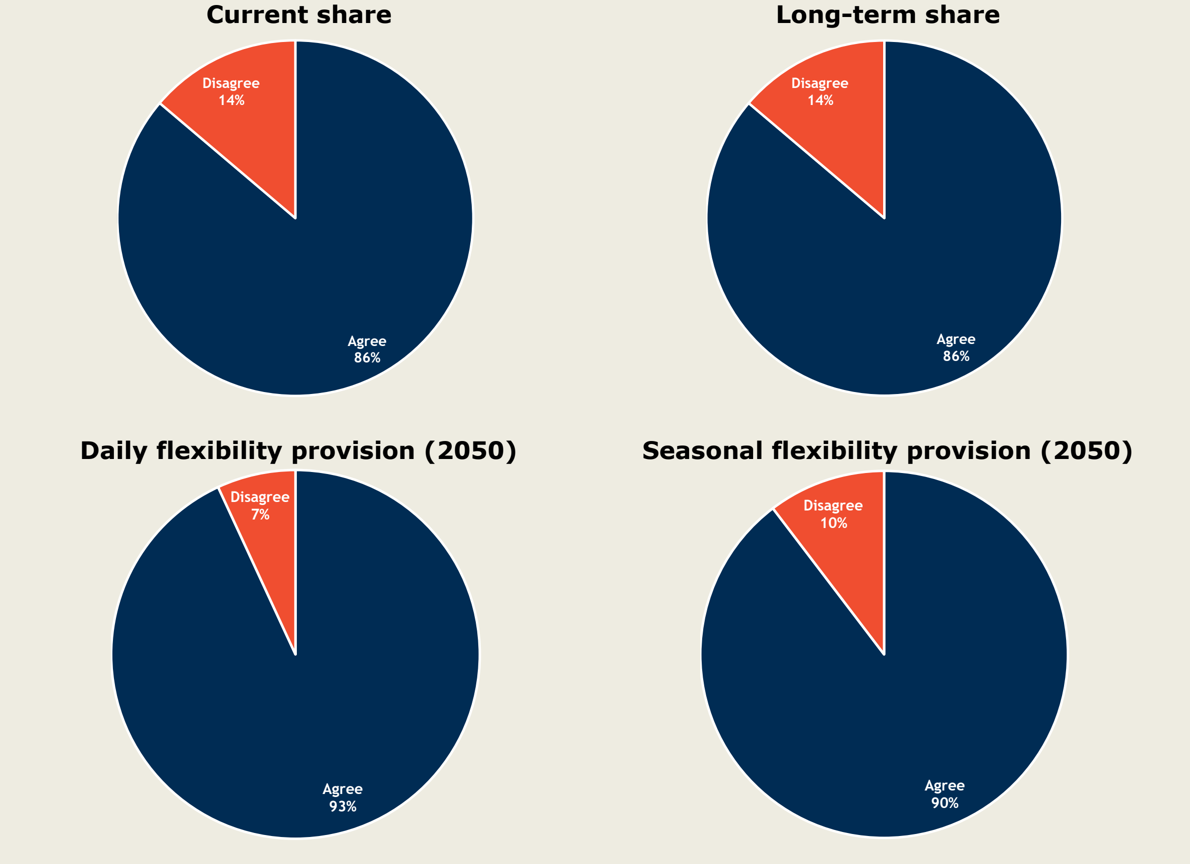
Due to the uncertainty in defining the future share, a respondent suggested employing only the current share, but updating it regularly. However, this would significantly underestimate supply chains related to e.g. electrolysis or CCS for example. Nonetheless, regular updates of the criticality assessment are desirable to reflect future developments.

Most respondents agreed with the use of seasonal and daily flexibility provision as indicators to measure strategic importance (flexibility provision has been summarised as a single indicator). A respondent supported the use of qualitative indicators, such as the industrial potential in the EU – this is considered through indicator 4 presented in Figure 4-4.

361 See, for example, European Commission. (2017). Mainstreaming RES: Flexibility portfolios. Available at: https://ec.europa.eu/energy/sites/ener/files/mainstreaming_res_-_artelys_-_final_report_-_version_33.pdf

362 For example, building shell technologies and efficient appliances/equipment cover a wide range of technologies, have limited repair needs or are passive once installed and/or built.

Figure 4-4 Survey answers to using strategic importance and vulnerability to determine the critical supply chains ($n_{respondents}$ = 29)



4.1.3. Vulnerable supply chains or elements identification

Supply chain characterisation and definition of vulnerability criteria

When characterising the supply chains, we conducted the analysis based on the same supply chain building blocks (stages), shown Figure 4-5. The supply chain stages proposed below might not be applicable to all supply chains supply chains in the long list, especially for overarching energy technologies like smart buildings or digital technologies. For such cases, we modified or excluded the supply chain stages appropriately.

For each of the stages of the supply chain we looked at the needs and flows for the following elements:

- Raw and processed materials, (sub-)components, assemblies and equipment;
- Know-how / Information;
- Specialised services (e.g. digital, highly-qualified skills).

Figure 4-5 Overarching stages for supply chain characterisation

We kept separate the raw materials stage of the supply chain from the provision of intermediary products from processed materials and components from heavy industry, and from downstream stages in the supply chain, i.e. the operation and maintenance, as well as the decommissioning and circularity stages. This was done because, in contrast to other stages in the supply chain which are more technology-specific, critical raw materials can be relevant to a number of supply chains. Furthermore, the relevant issues and policy aspects to be addressed with regards to raw materials might differ from those related to provision of intermediary products from upstream heavy industry.

The table below lists the 2020 critical raw materials of high economic importance to various EU sectors identified by the European Commission.[363,364]

Table 4-3 List of Critical Raw Materials in 2020[365]

2020 Critical Raw Materials		
Antimony	Hafnium	Phosphorus
Baryte	Heavy Rare Earth Elements	Scandium
Beryllium	Light Rare Earth Elements	Silicon metal
Bismuth	Indium	Tantalum
Borate	Magnesium	Tungsten
Cobalt	Natural Graphite	Vanadium
Coking Coal	Natural Rubber	Bauxite
Fluorspar	Niobium	Lithium
Gallium	Platinum Group Metals	Titanium
Germanium	Phosphate rock	Strontium

For the purpose of this study, we did not focus on the operation and maintenance stage of the supply chains since the level of risks and the types of vulnerabilities experienced by the operators or providers of services would have been addressed in their own risk assessments and business continuity plans. Nonetheless, specific vulnerabilities in operation and maintenance are highlighted, in case it relates to e.g. availability of spare parts, consumables (other than fuels), and skilled workers[366].

Likewise, given that the end-of life (decommissioning/recycling/disposal) portion of the supply chain is not critical to short-term security of supply, we focused on the detailed analysis on the remaining components of the supply chain. However, boosting resource efficiency and promoting recycling is one of the three targeted measures of the 2008 European Raw Materials Initiative[367] to secure and improve access to raw materials for the EU. In addition, given the potential of recycling and broader circularity measures to address supply chain vulnerabilities, these are addressed as a specific strategy to mitigate vulnerabilities under chapter 3.

To determine vulnerability per element in the supply chain we assess the criteria listed in the table below.

Table 4-4 List of criteria and metrics to assess supply chain elements vulnerability

Criteria	Proposed metric
Import dependency	- Import share - Number of importers/sources
Extent of know-how/specialisation in Europe	Using EU patents as proxy / other
Market concentration	Number of manufacturers/suppliers
Ease of substitutability	Based on evidence from stakeholder interviews[368]
Price stability of elements in the supply chain	Historic price trends

We used expert judgment to assess the vulnerability level per criteria to each of the elements in the supply chain stages. Considering the indicators and other qualitative aspects, including the feedback from stakeholders, the vulnerability of the supply chains was defined according to the number of

[363] European Commission. (2020). COM(2020) 474 final. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0474
[364] The Critical Raw Material list considered the economy as a whole and thus encompasses other sector than just the energy sector.
[365] European Commission. (2020). COM(2020) 474 final. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0474
[366] SWD(2020) 104 final. Energy security: Good practices to address pandemic risks. Available at: https://ec.europa.eu/energy/sites/ener/files/1_en_document_travail_service_part1_v3.pdf
[367] European Commission. (n.d.). Policy and strategy for raw materials. Available at: https://ec.europa.eu/growth/sectors/raw-materials/policy-strategy_en
[368] Additional guidance from - Pavel C; Marmier A; Alves Dias P; Blagoeva D; Tzimas E; Schuler D; Schleicher T; Jenseit W; Degreif S; Buchert M. (2016). Substitution of critical raw materials in low-carbon technologies: lighting, wind turbines and electric vehicles. EUR 28152 EN. Publications Office of the European Union; JRC103284 and European Commission – DG RTD. (2017). Study on energy technology dependence. Available at: https://op.europa.eu/en/publication-detail/-/publication/344b4c68-538f-11ea-aece-01aa75ed71a1

vulnerable elements and their vulnerability level. Finally, supply chains which are considered to be of strategic importance and to have vulnerable elements were defined as critical.

4.2. Assessment of current and potential problems for critical supply chains

Chapter 2 identifies both current and potential vulnerabilities of the critical EU energy supply chains, in different threat scenarios - including pandemics as well as three other threat scenarios. Chapter 2 is divided into two sub-sections. Section 2.1 focuses on identifying the vulnerabilities that have been exposed or exacerbated as a result of the **COVID-19 pandemic** situation. Section 2.2 identifies and analyses the vulnerabilities of the critical energy supply chains in **other plausible threat scenarios**: extreme weather events, cyber threats and geo-political tensions.

4.2.1. Evaluation of problems and delays incurred since the onset of COVID-19

The objective of section 2.1 is to examine supply chain problems which have occurred since the start of the COVID-19 crisis. This includes both supply chain problems affecting the overall energy system as well as affecting specific strategic supply chains. It also includes problems experienced at different levels—globally, within the EU, and specific EU regions and Member States. This process is expanded in section 2.2 to include issues that could arise in the critical energy supply chains due to three other threats, beyond a pandemic situation (COVID-19). The outcome of chapter 2 identifies the vulnerable elements in the critical list of energy technology supply chain stage(s), and their root cause(s).

These issues are further characterised and described in a concise summary table presenting the key impacts of COVID-19 on the critical list of EU energy technology supply chains since the onset of the pandemic, including the following:

- Key impacts of COVID-19 on the energy supply chains;
- Description of impacts;
- Main supply chain stages impacted;
- Examples of supply chains affected;
- Root cause of vulnerability;
- Summary of actions that have been taken to date, and/or any policy recommendations[369].

The main sources for this review are:

- Cross-technology impacts
    - Documents on the impacts of the COVID-19 crisis;
    - Documents on the actions taken and/or recommended actions;
    - Inputs regarding the overall resilience of the EU energy system or applicable to multiple supply chains received from stakeholders.
- Supply chain-specific impacts for identified critical supply chains
    - Documents on the impacts of the COVID-19 crisis;
    - Documents on the actions taken and/or recommended actions;
    - Survey inputs specific to the identified critical supply chains;
    - In-depth interviews with stakeholders of the identified critical supply chains.

4.2.2. Expanding inventory with problems for 3 other threats scenarios

Section 2.2 expands on the vulnerabilities of the energy technology supply chains identified in section 2.1 by anticipating other problems which could arise due to new threats and unidentified vulnerabilities in the EU energy technology supply chains.

The focus of the analysis of impacts of the threat scenarios is on the *functioning* of all supply chains stages, i.e. sourcing, installation and eventual impacts on O&M and decommissioning (e.g. due to difficulties in supplying spare parts), *rather than on the operation or decommissioning* of the installed assets themselves.

The specific steps for conducting the analysis are as follows:

1. Select three threats scenarios relevant to the energy supply chains for analysis based on past events and/or demonstrated impacts
2. State specific hazards for each threat scenarios which could impact energy supply chains – for example extreme weather events hazards in the case of climate change.
3. Describe threat scenarios and hazards in detail, to be used in the analysis of how they affect supply chains
4. Populate and expand the inventory of supply chain issues with available information sources (described below) for each threat. This means adding new database entries for new potential

[369] This compilation supports the development of policy recommendations for chapter 3.

issues as well as assessing whether any already identified issues are also applicable to other threats.
5. Analyse the impacts of the threat scenarios on EU energy supply chains, both generally and per supply chain.
6. Update the vulnerabilities per supply chain according to identified impacts of hazards

Definition and description of threat scenarios (steps 1-3)

A long list of threat scenarios for consideration was shared with the Commission, and was presented to the stakeholders during the first webinar to gather any feedback on the proposed list. The final list of threat scenarios comprises of:

- Pandemics (represented by the COVID-19 crisis, and as discussed in section 2.1), including of persistent kind;
- Extreme weather events;
- Cyber threats;
- Geo-political tensions.

The identified threat scenarios are based on the likelihood of the risks to the EU energy supply chain as evidenced by past events which caused disruptions (e.g. geo-political tensions) and/or demonstrated impacts expected to affect the energy technology supply chain (in the case of extreme weather events). The selection of these scenarios is not an indication of any expectation that they are likely to occur, but rather, they serve to identify potential vulnerabilities and strengthen the EU energy supply chains.

Description of hazards per threat scenario

The following are the hazards identified for each threat scenario. The threat scenarios and the hazards are further elaborated in Section 2.2.

- Persistent pandemics
  - Extra-EU border closures
  - Intra-EU border closures
  - Restricted access to work sites
  - Logistical issues
  - Public administration delays
  - Shortage of Personal Protection Equipment (PPE)
- Extreme weather events
  - Extreme temperatures
  - Extreme rainfall / floods
  - High-intensity hurricanes
- Cyber attacks[370]
  - Unintentional vulnerabilities in hardware/software
  - Lack of security updates/patches for identified vulnerabilities
  - Backdoors / hidden functions in hardware/software[371]
  - Large-scale deployment of end-point digital equipment
  - Vulnerabilities of 3rd party service providers
- Geo-political tensions
  - Supply route disruptions
  - Tariff increases
  - Trade sanctions
  - Export restrictions introduced by countries that are strategic exporters

Expansion of the inventory of supply chain issues (step 4)

Potential issues arising from the hazards identified per threat scenarios were assessed against other threat scenarios. For example, the issues arising due to COVID-19 were assessed for the possibility that the same issue would arise in the other threat scenarios, for e.g. geo-political tensions. For example, disruptions due to border closures observed during the pandemic, could also become a concern under a geo-political escalation scenario.

The main data sources for populating the database of supply chain issues arising from the three threats and for conducting the analysis were:

1. Desk research of existing literature on the vulnerabilities of the selected threat scenarios, separated by:

[370] Other cybersecurity issues not related to supply chains (e.g. direct cyber attacks to an energy company's system) is out of scope of this assessment.
[371] Hidden functions are hardware capabilities such as Wi-Fi which are a factory standard but not activated for a specific equipment. It can be activated and used by a malicious actor to gain access to the equipment.

- Cross-supply chain literature, covering the impact of the threats on multiple supply chains
- Supply chain-specific literature – collected by the team expert on the specific supply chain

2. In-depth interviews with various experts of the EU energy sector. Individual fiches for the energy technologies were prepared and shared with our interviewees ahead of the interview. The updated fiches are presented in Annex B.
3. Expertise of the consultancy for developing the vulnerability analysis for each of the strategic supply chains.
4. Analysis for the extended pandemic based on the findings gathered in section 2.1.

Analysis of hazard impacts on energy technology supply chains (step 5)

The analysis of section 2.2 is carried out in two steps:

1. Per threat scenario, as the hazards of each of the threat scenarios are likely to affect multiple energy supply chains in a similar way;
2. With additional analysis per hazard to identify specific supply chains particularly affected, where applicable.

4.3. Identification of possible measures to mitigate the identified risks and reinforce the resilience of the critical supply chains for energy security

Chapter 3 identifies a list of short-term and long-term policy recommendations (with a focus on EU-level measures) to mitigate risks and to strengthen the resilience of the most critical energy supply chains and sectors within the EU. Recommendations are categorised, among other aspects, according to whether they refer to the continuation of existing measures, to the improvement of new policy measures, or to new measures.

The definition of recommendations employed the following steps:

1. Identify the main vulnerabilities of critical elements and related threats, either per supply chain or for cross-supply chain aspects (such as for raw materials or monitoring aspects), as well as the vulnerability root cause(s) – section 3.1;
2. Identify main problem areas representing the most important vulnerability issues from one or more critical supply chains;
3. Develop a list of existing and potential policy measure categories addressing entirely or partially the main problem areas identified in step 2;
4. Categorise and short-list measures based on the:
    a. Main vulnerabilities of chapter 1 addressed;
    b. Importance of targeted hazards' impacts;
    c. Whether vulnerabilities and risks identified were sufficiently addressed by existing measures (i.e. whether there was a policy gap);
    d. Feasibility of implementation.

This process allowed for the mapping of each recommendation to the relevant problem area as well as to the vulnerable elements of the critical supply chains. The considered policy measures are detailed in Annex E. The final short-listed measures are presented in chapter 3.2. Each short-listed measure was detailed according to the following aspects, with a summary table for each measure:

- Problem area description;
- Existing policy instruments;
- Policy gap;
- Necessity and EU added value to act;
- Objectives and description of recommended policy measures;
- Impact of policy measure;
- Best practices.

4.4. Stakeholder engagement plan

Stakeholder engagement activities were conducted throughout the project. These are described below, and detailed in Table 4-5.

Online survey

The online survey was launched on September 18th, 2020, and closed on October 16th, 2020. A total of 49 responses were received.

Webinar #1

The first webinar was held on October 15th, 2020, from 09h30—12h00 CEST via Zoom platform. The webinar was attended by members of the project team from DG ENER, Trinomics and Artelys, and 46 participants representing various stakeholder groups.

Webinar #2

The second webinar took place on December 2nd, 2020, from 09h30—12h00 CEST via Zoom. It counted with 23 participants from EU organisations (Commission and European External Action Service) and 52 from external organisations.

Webinar #3

A third webinar focusing on policy measures took place on February 11th, 2020, from 14h30 to 17h30 CET via Zoom. A policy paper was elaborated so that stakeholders could provide feedback during the webinar and in written form. The webinar counted with 14 participants from EU organisations (Commission and European External Action Service) and 38 from external organisations.

Interviews and written feedback

For each strategic supply chain, a fiche with questions and a draft analysis of the vulnerabilities was sent to relevant stakeholders. For some, follow-up interviews were conducted.

Table 4-5 Project stakeholder engagement activities

Activity	Chapter(s)	Date	Stakeholders involved
Online questionnaire	All	18 Sep-16 Oct	• Government authorities and energy regulators, industry and associations for all considered supply chains, network operators, NGOs and other stakeholders.
Interviews	2 & 3	November - January	• Based on results of interview and webinar.
Discussions with coordination groups (electricity)	1	22 September	• Electricity Coordination Group • EC (project team)
Discussions with coordination groups (gas)	1	6 October	• Gas Coordination Group • EC (project team)
Webinar 1	1	15 October	• Electricity and Gas Coordination Groups • Stakeholders involved in questionnaire/interviews • EC (Extended Steering Committee)
Webinar 2	2	2 December	• Electricity and Gas Coordination Groups • Stakeholders involved in questionnaire • EC (Extended Steering Committee)
Webinar 3	3	11 February	• Electricity and Gas Coordination Groups • Stakeholders involved in questionnaire/interviews • EC (Extended Steering Committee)

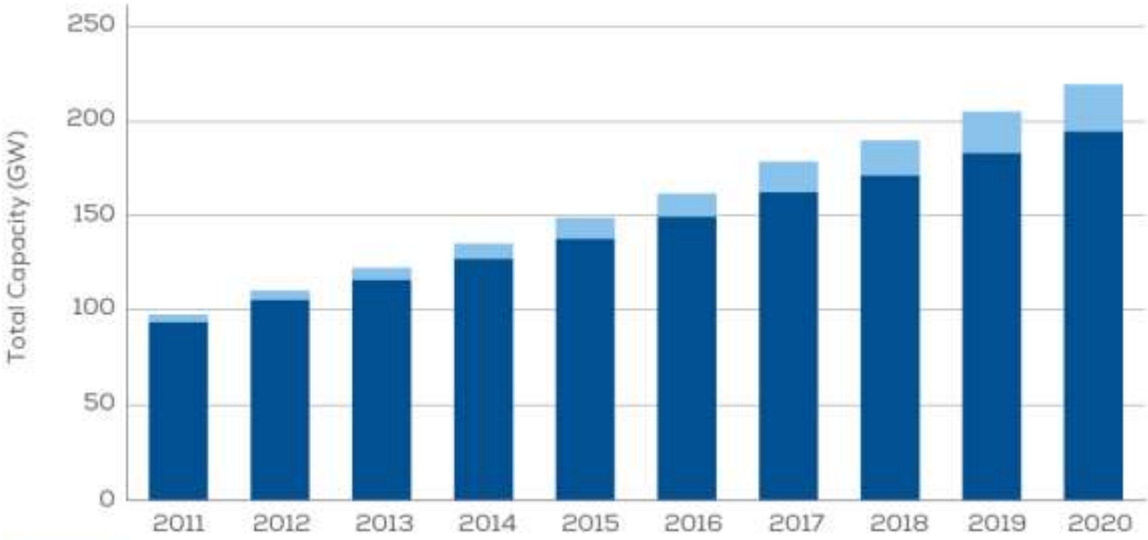
5. Annex B: High-level assessment of vulnerabilities per supply chain

5.1. Wind energy – onshore/offshore

Introduction and technology description

With a total net installed capacity of 220 GW in 2020 (EU27 +UK) (179 GW in EU27), wind energy is a major form of power generation capacity in Europe. Europe installed 14.7 GW of new wind power capacity during 2020, 6% less than in 2019 and 19% less than expected pre-COVID-19. In 2020, wind accounted for 16% of the electricity consumed by Europe (EU27 +UK).[372]

Figure 5-1 Total wind installations in Europe (EU27 +UK)[373]

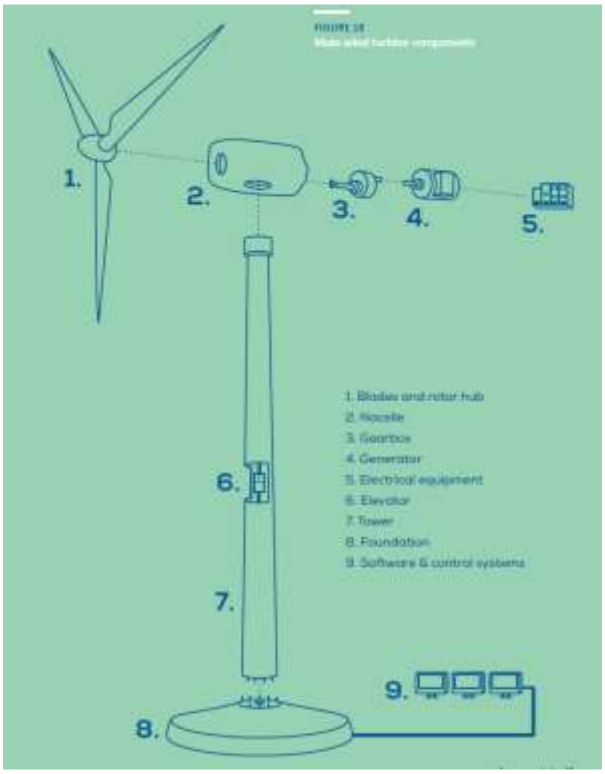


	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Offshore	4	5	7	8	11	13	16	18	22	25
Onshore	94	105	116	127	137	149	162	171	183	195
Total	98	110	123	135	148	162	178	189	205	220

Wind turbines have become a mature and highly sophisticated electricity generation technology. Current developments are aimed at cost reductions and efficiency improvements to meet ambitious targets for reduction of the cost of electricity generated. Every part and component of the wind turbine plays a significant role in how efficient a wind turbine operates. The basic elements of the wind turbine are the blades, the rotor hub, the rotor shaft, the nacelle, the rotor brake, the gearbox, the generator and controller, the tower and the transformer. These elements are depicted in Figure 5-2.

[372] WindEurope. (2021). Wind energy in Europe: 2020 Statistics and the outlook for 2021-2025.
[373] Ibid.

Figure 5-2 Main components of a wind turbine [374]



Wind power systems can be classified based on their installation characteristics: onshore or offshore. Offshore wind speeds are typically much higher and more constant than onshore wind speeds. In shallow waters (up to ~ 50 m), traditional fixed-bottom wind turbine technologies are preferred (with other conditions such as seabed geological conditions playing a role). For deeper-waters (over 40m) floating turbine technologies are being developed. As the name implies, fixed-bottom offshore technologies refer to structures where the foundation of the turbine is fixed to the sea floor. A number of solutions are presently available, including steel jacket structures, monopiles, gravity base structures, tripod piled and tripod suction bucket structures. Floating wind turbines are mounted on floating structures usually anchored to the ground via either tension-leg or catenary loose mooring systems. Currently the only floating wind farm at commercial scale in operation is located in Hywind, Scotland. It was developed by the Norwegian energy company Equinor (formerly Statoil).

The supply chain of wind energy

The wind energy value chain can be separated into the stages shown in Figure 5-4. Previous research[375][376] has identified several critically elements, predominantly, in the raw materials and compounds block of the supply chain.
The selection of the highly vulnerable elements is based on the assessment of the following criteria, but also on the literature review and stakeholder consultation.

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[374] WindEurope. (2017) Local impact, global leadership Available at: https://windeurope.org/about-wind/campaigns/local-impact-global-leadership/#report

[375] European Commission – DG RTD. (2017). Study on energy technology dependence. Available at: https://op.europa.eu/en/publication-detail/-/publication/344b4c68-538f-11ea-aece-01aa75ed71a1

[376] Blagoeva D; Alves Dias P; Marmier A; Pavel C. (2016). Assessment of potential bottlenecks along the materials supply chain for the future deployment of low-carbon energy and transport technologies in the EU: Wind power, photovoltaic and electric vehicles technologies, time frame: 2015-2030 . EUR 28192 EN. Luxembourg (Luxembourg): Publications Office of the European Union; JRC103778

Figure 5-3 Vulnerabilities in the wind supply chain[377]

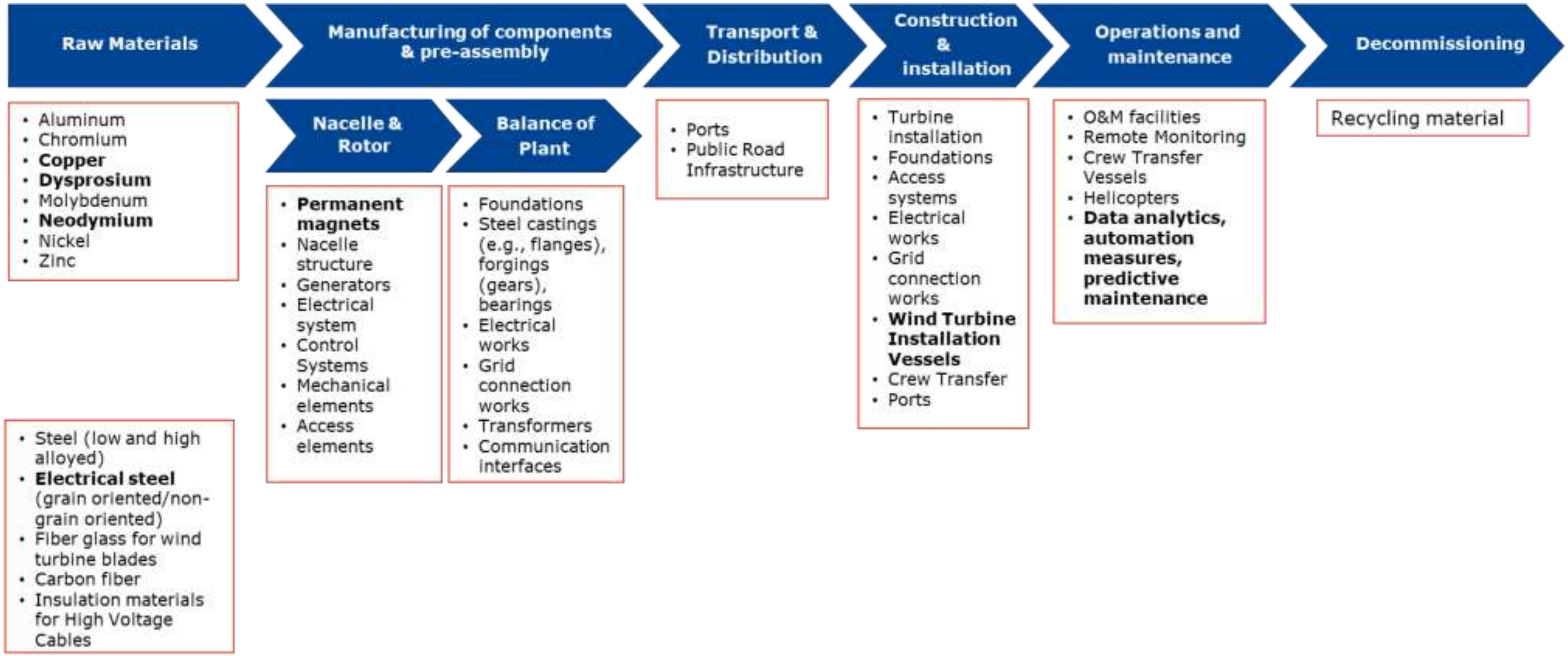
	Supply chain stage	Vulnerable element	Import dependency	Market concentration	Easy of substitutability	Price stability
			Import reliance	CR4 / Main suppliers	Qualitative analysis	Coefficient of variation
Wind	Row / processed materials	Aluminium	59%	43% (RU, DE, MZ, FR)	Medium, by copper	22%
		Chromium	66%	86% (ZA, TR, KZ, IN)	Low	Overall increase from 2012 to 2017
		Copper	44%	58% (PL, CL, PE, ES)	Medium, by aluminium	42%
		Dysprosium	100%	97%	Substitutes being developed, work-in-progress	Overall increase
		Molybdenum	100%	73% (US, CL, CA, PE)	Low - alternatives are associated to and/or loss in performance and higher cost	NA
		Neodynium	100%	97%	No options for substitution at an acceptable price	Overall increase
		Nickel	59%	59% (CN, RU, JP, CA)	Medium	50%
		Zinc	60%	64% (CN, AU, PE, US)	For corrosion protection Zi coating is substituted by Al alloys (less effective), Cd, paint and plastic coatings (less durable)	40%
		Concrete(gypsum, limestone)	~0-5%	NA	NA	NA
		Fiber glass	~35% (Avg. 2012-2015)	87%	Carbon fibre can be a stable and substitute material.	NA
		Steel	Net importer in 2019	NA	NA	NA
		Insulation materials for HVDC	Low	91%	Ethylene Propylene Rubber (EPR) and P-laser technology have a high potential to act as substitute for XLPE insulator material	NA
	Components / Equipment / Assembly	Wind turbine (as a whole)	Low	~ 50%	NA	NA

377 Sources: Eurostat PRODCOM/COMEXT; JRC (2020) Study on the EU's list of Critical Raw Materials; other sources listed in section.

Some elements may appear to be highly vulnerable according to the assessment of these criteria, but for several other reasons (e.g. limited amount needed), both the literature and the stakeholders do not lead to the conclusion they should be considered as such. Therefore, these criteria should only be considered as a preliminary assessment of the vulnerability of the elements, which is refined with other information sources.

Vulnerable elements are highlighted in bold in the following Figure 5-4 illustrating the wind energy value chain.

Figure 5-4 The supply chain of wind energy



*Note: vulnerable elements found highlighted in **bold**.*

The main vulnerabilities, highlighted in bold in Figure 5-4, are developed below:

Raw Materials and compounds

In the raw material block of the supply chain the rare earth elements, **neodymium** (Nd) and **dysprosium** (Dy), have been identified as being at risk due to high import dependency. Wind turbine manufacturers use neodymium and dysprosium for their permanent magnets. The permanent magnets are an important component in a generator that may be used in two different types of wind turbines: hybrid systems that combine a gearbox with permanent magnets; and direct drive technologies that eliminate the gearbox. It is important to note that many EU generator manufacturers directly import the **permanent magnets** from suppliers in China and Japan rather than importing the unprocessed rare earth metals. Manufacturing of permanent magnets is not considered a vulnerability in itself but is rather based on issues related to the raw material dependencies.

In the current market, most of the operating and planned onshore wind turbines are still designed with gearboxes, whereas most of the offshore wind turbines have a direct drive technology and thus no gearbox or use a hybrid arrangement.[378] Currently, offshore direct drive models are widely designed with permanent magnets. In the case of both rare-earth materials used for manufacturing permanent magnets (Nd, Dy) the EU is fully reliant on non-EU suppliers which are heavily concentrated in a few countries with China being the dominant supplier in both cases. Difficulties to enter the market for new suppliers and the lack of suitable substitutes, in particular, for neodymium, result in a high overall risk of these dependencies. Recently, a trend towards resurgence of gearboxes in offshore designs (e.g. MHI Vestas, Siemens Gamesa) can be observed.

A study on the raw material needs and supply risks for the development of wind energy in Germany until 2050 identifies dysprosium and **copper** as the most critical materials. The paper forecasts an increase in cumulative demand for copper and dysprosium of 0.2% and 0.6% of current known reserves by 2050. The situation could become more complex given that copper and dysprosium used in permanent magnets are substitutes; generators without permanent magnets (i.e. without Dy) contain in exchange more copper windings.[379]

Although zinc is considered a widely available mineral which is also easily recyclable, the most recent analysis by the IEA on the role of critical minerals in the clean energy transition identifies zinc as a mineral with high importance for the wind technology supply chain. [380] Wind turbines rely heavily on zinc for coating of their steel components for corrosion protection. Given that the element is currently considered to be highly available, it does not constitute a vulnerability in the supply chain at present but monitoring of the future trends in the demand of this material should be considered.

Based on information received from interviews, **grain-oriented electrical steel** (GOES) is a crucial material in the wind industry used for the manufacturing of transformers as well as in wind turbines. A detailed analysis of GOES is conducted in the electricity networks supply chain fiche.

The EC Study on Energy technology dependence identified additional potential dependencies in the supply chain of wind energy related to: the insulation material for High Voltage (HV) electrical cables, the supply of fibre glass for wind turbine blades and the supply of Insulated Gate Bipolar Transistor (IGBT).[381]

High Voltage Direct Current (HVDC) insulation materials are primarily supplied from EU-based factories. The study concluded that the limited number of suppliers and the foreign ownership of the main suppliers does require monitoring the emergence of future dependency risks with respect to the development of this market. However, considering the stable competitiveness of the EU industry, there is little reason for concern at this moment. For fibre glass the dependency risk is somewhat higher due to the higher import share and the declining competitive position of the EU fibre glass industry.[382] But since there are good substitutes available that could become the new standard going forward, at present there is no need to manage this dependency actively. In the case if IGBTs, the

[378] JRC. (2016). Assessment of potential bottlenecks along the materials supply chain for the future deployment of low-carbon energy and transport technologies in the EU.
[379] Shammugam, Sh. et al. (2019) Raw metal needs and supply risks for the development of wind energy in Germany until 2050.
[380] IEA. (2021). The Role of Critical Minerals in Clean Energy Transition
[381] European Commission – DG RTD. (2017). Study on energy technology dependence. Available at: https://op.europa.eu/en/publication-detail/-/publication/344b4c68-538f-11ea-aece-01aa75ed71a1
[382] European Commission – DG RTD. (2017). Study on energy technology dependence – Detailed assessment on dependencies within the wind energy, solar PV and battery energy storage value chain. Available at: https://op.europa.eu/en/publication-detail/-/publication/4d794ddb-5391-11ea-aece-01aa75ed71a1/language-en

study concluded that there is little reliance on non-EU suppliers and there is no sign of declining competitiveness of the EU industry. Furthermore, the ease of market entry is judged to be high, which further reduces the risk of any dependencies.

Component manufacturing and integration

WindEurope's "Local impact, global leadership" report found that in 2016 Europe was a global net exporter with a positive trade balance of EUR 2.4 billion. Figures 5-5 & 5-6 illustrate wind energy import and export flows between the EU28 and the rest of the world in 2016.

The European manufacturers account for about 35% of the global wind turbine value chain. They are only superseded by manufacturers from China who dominate the global manufacturing of components with almost 50%. The European wind industry has high manufacturing capabilities in components with a high value in wind turbine cost (e.g. towers, gearboxes and blades), and in components with synergies to other industrial sectors (generators, power converters and control systems). The EU Strategy on offshore renewable energy highlights that the EU is a global leader in renewable energy offshore technology and industries. Especially, Europe can benefit from a first-mover advantage in bottom-fixed wind turbines given the strong home market.[383] In 2019, about 93% of the total offshore installed capacity was produced by European manufacturers.[384] Analysis by the EU's Joint Research Centre shows that the European manufacturers exhibit overcapacities in all key wind turbine components, when compared to the present and future European demand, at deployment rates between 12.1 and 22.7 GW/year. Expected deployment rates at global level suggest that there could be an additional market potential for European manufacturers outside of Europe.[385] However, given the EU's increased climate ambitions which will go hand in hand with an accelerated deployment of renewables (e.g. see Offshore renewable energy strategy objectives of at least 60 GW offshore and by 2030 and 300 GW by 2050), it is likely that these additional capacities will be required in Europe.

Furthermore, of the 10 biggest wind turbine manufacturers in the world, five of them are based in the EU. The largest wind-turbine makers outside of China are heavily concentrated in Europe: Vestas Wind Systems A/S is based in Denmark and Siemens Gamesa Renewable Energy SA in Spain, while GE Renewable Energy (wind subsidiary of General Electric Co.), is headquartered in France. Between them, the three companies sold 42% of all the wind turbines installed worldwide in 2019.[386]

[383] European Commission. (2020). SWD (2020) 273 final. An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future. Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=SWD:2020:273:FIN

[384] European Commission. (2020). Progress of clean energy competitiveness. Available at: https://ec.europa.eu/energy/topics/technology-and-innovation/clean-energy-competitiveness_en

[385] Telsnig, T. and Vazquez Hernandez, C. (2019). Wind Energy: Technology Market Report, EUR 29922 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-12570-9, doi:10.2760/260914, JRC118314.

[386] Rack, Y. (2020). European wind industry braces for coronavirus hit as supply chains suffer. Available at: https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/european-wind-industry-braces-for-coronavirus-hit-as-supply-chains-suffer-57593957

Figure 5-5 Number of companies manufacturing main wind turbine components[387]

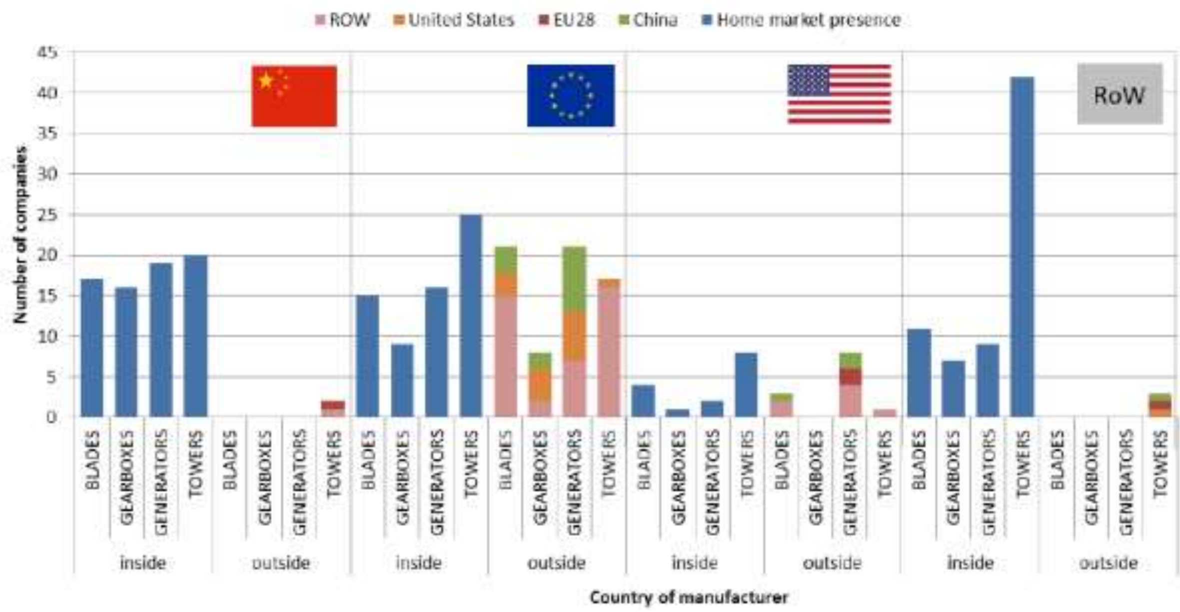
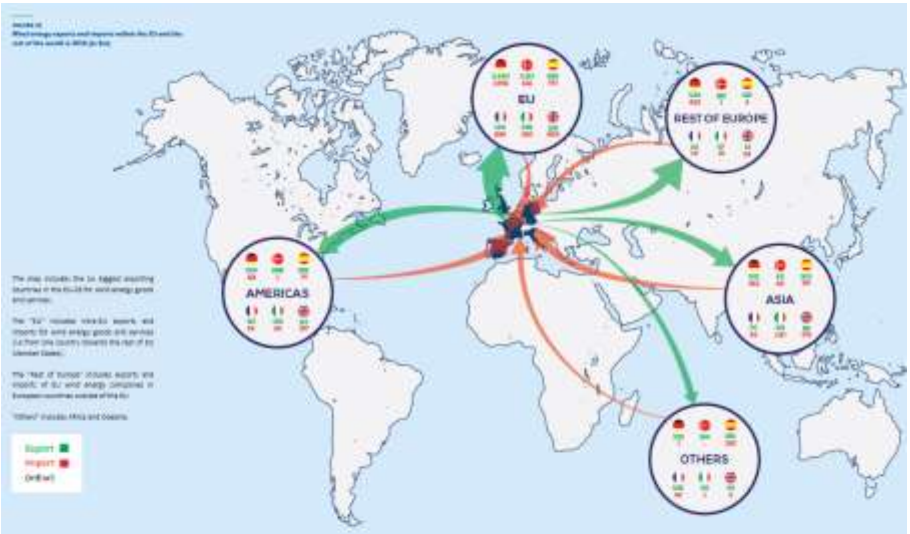


Figure 5-6 Wind energy exports and imports within the EU28 and the rest of the world in 2016[388]



Construction and installation

In the offshore wind sector wind turbine installation vessels (WTIV) (also called jack up vessels) used for the installation of offshore wind turbines represent an important consideration in terms of costs and planning. Jack up vessels cost ~USD 335 million, they can be rented for ~ USD 220, 000/day. Currently there are only 16 vessels worldwide. Logistics associated with securing a WTIV in time can affect a bidder's ability to win projects.[389] Companies like Jan de Nul build vessels based only on certain demand, forecasting demand is challenging and may not align with turbines demand (turbine design is ahead of vessel designs). Countries such as Taiwan and China are building their own WTIVs, decreases the supply chain risks.

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387 Telsnig, T. and Vazquez Hernandez, C. (2019). Wind Energy: Technology Market Report, EUR 29922 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-12570-9, doi:10.2760/260914, JRC118314.

388 WindEurope. (2017). Local impact, global leadership Available at: https://windeurope.org/about-wind/campaigns/local-impact-global-leadership/#report

389 Søfart. (2020). Offshore wind turbine manufacturer: We are missing installation vessels now (Danish). Available at: https://www.soefart.dk/article/view/736115/havmolleproducent_vi_mangler_installationsskibe_nu

Digitalisation of O&M and cybersecurity considerations

Data analytics, automation measures and predictive maintenance will become increasingly important for the efficient performance of operation and maintenance of both onshore and offshore wind. For offshore wind where the O&M costs are generally higher due to more expensive maintenance and logistics procedures and complications related to shortages of skilled workers, digitalisation and predictive maintenance are promising options. Digitalisation has and will continue to also an important role during the COVID-19 pandemic, allowing companies to maintain continuity of operations.[390]

Wind farms are especially vulnerable to cybersecurity concerns for several reasons:

- The approach for cyber security was focussed on (information technology) IT mainly, without developing a different approach for operations technology (OT)
- Old wind parks, are based on communication systems, never designed with the "security by design" mindset
- Operational technologies like (supervisory control and data acquisition) SCADA and their substations for offshore wind parks need a different approach than that used for IT security
- Vendor's remote access is not always managed properly (segregation of duties)
- Communication links to the windfarms can be realized by more than one provider without notification
- Use of outdated communication protocols and lack of security enhancements and updates[391]

Evidence of short-term vulnerability to the COVID-19 pandemic

Europe installed 14.7 GW of new wind power capacity during 2020, this is 19% less than forecasted before the COVID-19 pandemic.[392]

The wind industry reported major supply chain disruptions in relation to the COVID-19 pandemic in the first semester of 2020. These disruptions were related in particular to imports of raw materials and other subcomponents as well as the production and assembly of wind turbine components.[393] January and February were months in which China experienced a peak in the COVID-19 outbreak. During these months exports of key wind components to Europe were affected. In India, the world's largest manufacturer of wind turbine gearboxes, the lockdown resulted in the temporary closure of some manufacturing plants, which influenced European imports.

In Europe, the most severe disruptions took place in early April when 19 manufacturing sites were temporarily closed in Spain and Italy. The restrictions in the free movement of people and goods had also negative impacts on the O&M services and the commissioning of onshore and offshore wind in Europe.

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[390] WindPower monthly. (2020). 'Growing cyber threat' during coronavirus pandemic. Available at: https://www.windpowermonthly.com/article/1688098/growing-cyber-threat-during-coronavirus-pandemic

[391] DNV GL. (2020). Why windfrarms need to step up cyber security: hacking an entire farm of wind turbines may be easier than you think. Available at: https://www.dnvgl.com/article/why-windfarms-need-to-step-up-cyber-security-128082

[392] WindEurope. (2021). Wind energy in Europe: 2020 Statistics and the outlook for 2021-2025. Available at: https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-in-2020-trends-and-statistics/

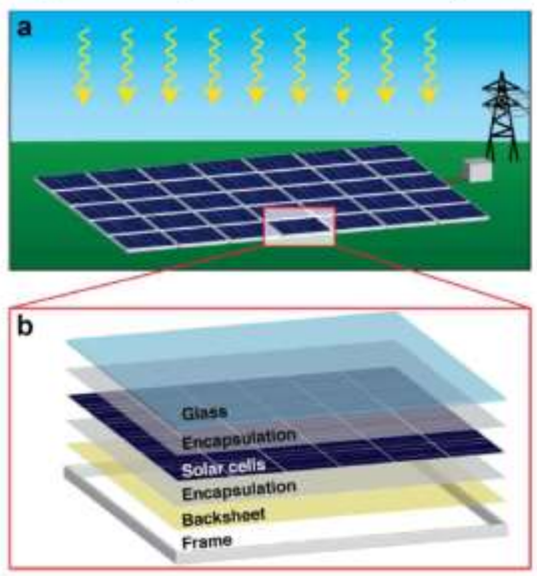
[393] WindEurope. (2020). The impact of Covid-19 on Europe's wind sector. Available at: https://windeurope.org/intelligence-platform/product/the-impact-of-covid-19-on-europes-wind-sector-exec-summary/#:~:text=In%20spite%20of%20the%20very,economic%20shock%20it%20has%20produced.

5.2. Solar photovoltaic

Introduction and technology description

Solar photovoltaic (PV) refers to any technology that converts light into electrical energy using semiconductor materials that exhibit the photovoltaic effect (creation of electrical voltage and electric current upon exposure to light). The individual solid state devices converting light to electricity are called solar (or photovoltaic) cells, and an array of many solar cells form the initial structure of a solar PV module. A solar PV system includes one or more solar modules, and other elements such as supporting structure, cables and inverters, and is designed to produce specific power and voltage output.

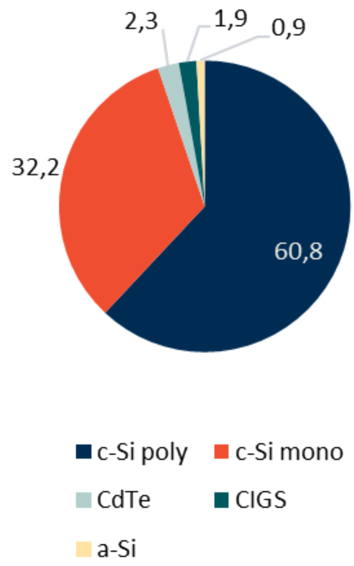
Figure 5-7 Illustration of a PV panel[394]



There are a variety of different solar PV technologies, which are commonly differentiated by the semi-conducting materials used for the modules. The two most common sub-groups are: crystalline silicon (c-Si), and thin-film materials such as Cadmium telluride (CdTe), Copper Indium Gallium Selenium (CIGS), amorphous silicon (a-Si), organic materials (polymers or perovskites) and III-V materials. As shown in Figure 5-8, crystalline silicon technologies represent 95% of global annual production (poly and mono combined). All thin-film technologies together constitute around 5% of global production (Fraunhofer ISE, 2018). According to a recent JRC study, under a high demand scenario (based on 55% GHG reduction target by 2030 and almost complete decarbonisation by 2050), the share of thin-film technologies could increase up to 23% by 2050 (JRC, 2020). [395]

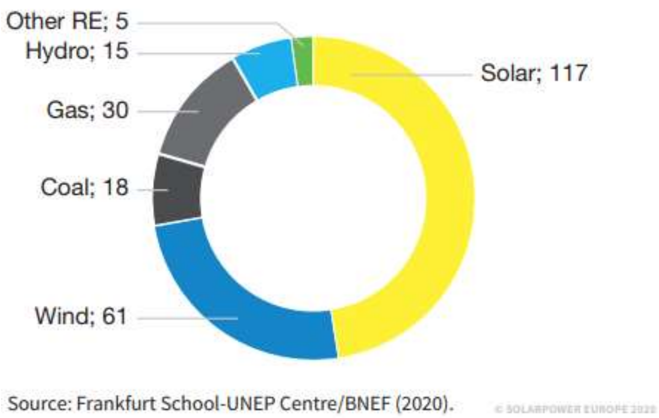
[394] Carrara, S., Alves Dias, P., Plazzotta, B. and Pavel, C. (2020). Raw materials demand for wind and solar PV technologies in the transition towards a decarbonised energy system, EUR 30095 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-16225-4 (online), doi:10.2760/160859 (online), JRC119941. Available at:
https://publications.jrc.ec.europa.eu/repository/handle/JRC119941#:~:text=Innovation%20and%20growth-,Raw%20materials%20demand%20for%20wind%20and%20solar%20PV%20technologies%20in,towards%20a%20decarbonised%20energy%20system&text=As%20result%2C%20the%20consumption%20of,drastically%20in%20the%20coming%20decades.
[395] Ibid.

Figure 5-8 Percentage of 2017 global annual production per PV technology[396]



The PV market has moved from early and expensive niche market developments in the 1990s to a large-scale, globally deployed and increasingly competitive market. This development has been accompanied by technological progress, economies of scale and strong policy support. In 2019, the solar power sector increased by 13% to 116.9 GW.[397] As seen from the picture below, this figure represents almost half of the global new power plant capacity installed in 2019.

Figure 5-9 Net power generation capacity added (GW) in 2019 by main technology[398]



Despite the impressive annual growth, the cumulative share of solar PV in installed capacities is still relatively small, accounting for 8.5% by the end of 2019. Furthermore, in terms of global power output solar PV generated merely 2.6%, and in Europe solar power amounted to around 4% of final electricity consumption.[399] Regarding forecasts for future growth, the IEA predicts that after 2020, net additions in Europe will increase steadily from 21 GW in 2021 to an average of 25 GW per year between 2023 and 2025.[400]

[396] Fraunhofer ISE. (2018). Photovoltaics Report. Available at: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf
[397] SolarPower Europe. (2020). EU Market Outlook for Solar Power 2019-2023.
[398] Ibid.
[399] European Commission. (2020). Shedding light on energy in the EU. Available at: https://ec.europa.eu/eurostat/web/products-interactive-publications/-/ks-02-20-278
[400] IEA. (2020). Renewables 2020. Available at: https://www.iea.org/reports/renewables-2020/solar-pv#abstract

The supply chain of solar PV

The solar PV supply chain can be divided in the elements depicted in Figure 5-10.

Figure 5-10 Vulnerabilities in the solar PV chain

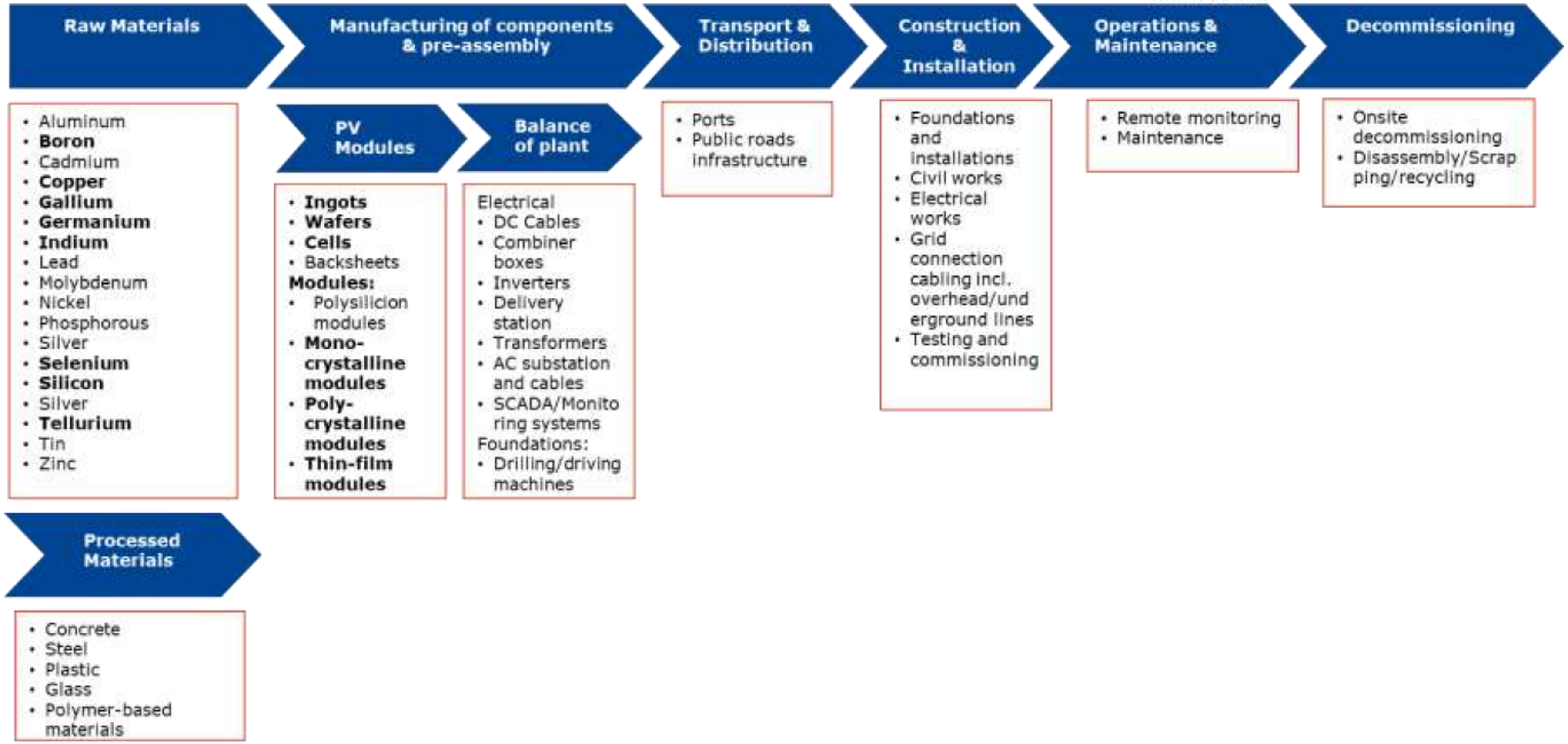
		Vulnerable element	Vulnerability criteria			
	Supply chain stage	Vulnerable element	Import dependency	Market concentration	Easy of substitutability	Price stability
			Import reliance	CR4 / Main suppliers	Qualitative analysis	Coefficient of variation
Solar PV	Raw / processed materials	Aluminium	59%	43% (RU, DE, MZ, FR)	Medium, by copper	22%
		Boron	100%	99% (TR, AR, NO, BO)	Low	Downward trend since mid-2000s
		Cadmium	6%	94% (NL, DE, PL, BG)	Medium	Downward trend
		Copper	42%	58% (PL, CL, PE, ES)	Medium, by aluminium	42%
		Gallium	31%	94% (DE, UK, CN, US)	Low	18-20% (4 years)
		Germanium	31%	89% (FI, CN, UK, RU)	Medium	14-17% (4 years)
		Indium	~43%	72% (FR, BE, UK, DE)	Low	~23% (4 years)
		Lead	18%	58% (DE, IT, ES, PL)	Medium	Lost ~ 25% of its value through 2018
		Molybdenum	100%	73% (US, CL, CA, PE)	Low - alternatives are associated to and/or loss in performance and higher cost	NA
		Nickel	59%	59% (CN, RU, JP, CA)	Medium	50%
		Phosphrous (elemental)	100%	98% (KZ, VN, CN)	Low	NA
		Silver	80%	82% (MX, PE, PL, AR)	Varies per application	Higher volaitility than gold
		Silicon metal	63%	68% (NO, FR, CN, BR)	Low	NA
		Selenium	17%	67 % (DE, BE, RU, FI)	High	Show high fluctuation
		Tellurium	100%	49% (UA, SE, CN, RU)	High but with loss of efficiency	NA
		Tin	78%	92% (US, PT, ES, TH)	High	All time high in 2011 and drop after
		Zinc	60%	64% (CN, AU, PE, US)	For corrosion protection Zi coating is substituted by Al alloys (less effective), Cd, paint and plastic coatings (less durable)	40%
		Steel	21%	44% (Extra-EU) (RU, TR, CN, UK)	Medium	21%
	Components / Equipment / Assembly	PV Cells	>90%	93%	High	NA
		PV Modules	65-80%	87%	High	NA
		PV Inverters	0%	78%	High	NA

Sources: Eurostat PRODCOM/COMEXT; JRC. (2020). Study on the EU's list of Critical Raw Materials; European Commission. (2020). Report on progress of clean energy competitiveness. COM(2020) 953; FastMarkets for price data of certain raw materials; other sources listed in section.

The selection of the highly vulnerable elements is based on the assessment of these criteria, but also on the literature review and stakeholder consultation. Some elements may appear to be highly vulnerable according to the assessment of these criteria, but for several other reasons (e.g. limited amount needed), both the literature and the stakeholders do not lead to the conclusion they should be considered as such. Therefore, these criteria should only be considered as a preliminary assessment of the vulnerability of the elements, which is refined with other information sources.

Vulnerable elements are highlighted in bold in the following **Figure 5-11** illustrating the solar PV value chain.

Figure 5-11 The supply chain of solar photovoltaics



*Note: vulnerable elements found highlighted in **bold**.*

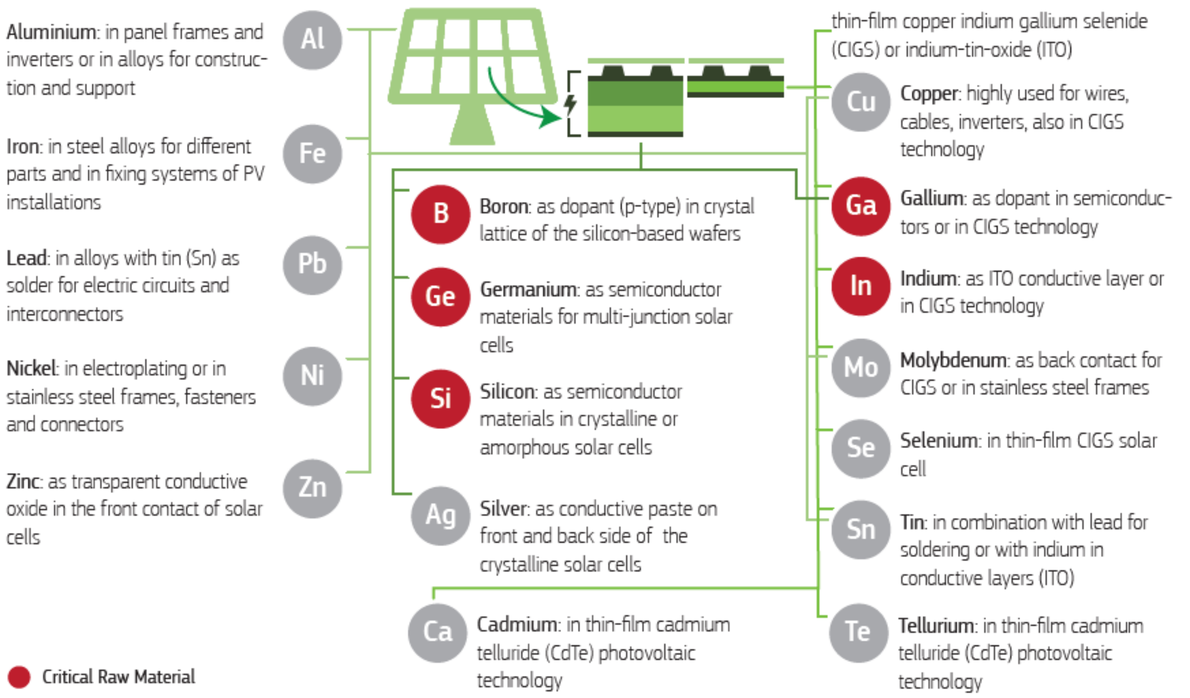
The main vulnerabilities, highlighted in bold in Figure 5-11, are developed below:

Raw materials

Critical raw materials

Thin-film technologies contain the most critical raw materials. The 2017 JRC report looked at thin-film PV technologies, copper-indium-gallium-selenide (CIGS) cells and cadmium telluride (CdTe) cells and identified the following as critical raw materials: boron (B), (as p-type dopant in the crystal lattice of the Si-based wafers), gallium (Ga) (as dopant in semiconductors or in CIGS), indium (In) (as indium-tin-oxide conductive layer in CIGS), germanium (Ge) (as semiconductor in multi-junction solar cells) and silicon (Si) (as semiconductor in crystalline or amorphous cells).[401] These same elements are again highlighted as the most critical in a more recent, 2020 study on critical raw materials for strategic technologies and sectors in the EU.[402] All five elements are part of the 2020 EU list of critical raw materials.

Figure 5-12 Raw materials used in solar PV technologies.[403]



Modelling forecasts foresee that in the case of a low demand scenario by 2050, the need for materials specific for PV cells might slightly decrease due to substantial improvements in material efficiency. This decrease in demand under such a scenario is also due to the assumption that thin-film technologies will continue to have a low market share. However, under the medium and high demand scenarios, the use of germanium could increase between 7.5 and 86 times by 2050.[404] Furthermore, under medium- and high- demand scenarios, significant material pressure is predicted for several materials, in particular, tellurium, indium, selenium and silicon. According to a recent analysis by the IEA, under certain scenarios, copper demand for solar PV is expected to more than double by 2040. In contrast, innovation to reduce mineral intensity could help to offset demand for silicon and silver.[405]

[401] Pavel, C. and Blagoeva, D. (2017). Materials impact on the EU's competitiveness of the renewable energy, storage and e-mobility sectors: Wind power, solar photovoltaic and battery technologies, EUR 28774 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-73491-5 (online),978-92-79-73506-6 (print), doi:10.2760/83521 (online),10.2760/938351 (print), JRC108356.
[402] JRC. (2020). Critical Raw Materials for Strategic Technologies and Sectors in the EU – A Foresight Study. Available at:
https://ec.europa.eu/docsroom/documents/42881/attachments/1/translations/en/renditions/native
[403] Ibid.
[404] Carrara, S., Alves Dias, P., Plazzotta, B. and Pavel, C. (2020). Raw materials demand for wind and solar PV technologies in the transition towards a decarbonised energy system, EUR 30095 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-16225-4 (online), doi:10.2760/160859 (online), JRC119941.
[405] IEA. (2021). The Role of Critical Minerals in Clean Energy Transition.

Structural materials

Regarding materials used in structural and electric components of PV power plants the JRC (2020) reports the following material intensities:

Table 5-1 Material intensities of key material for Solar PV[406]

Material/Element:	Material intensity
Concrete	60.7 t/MW
Steel	67.9 t/MW
Plastic	8.6 t/MW
Glass	46.4 t/MW
Aluminum	7.5 t/MW
Copper	4.6 t/MW

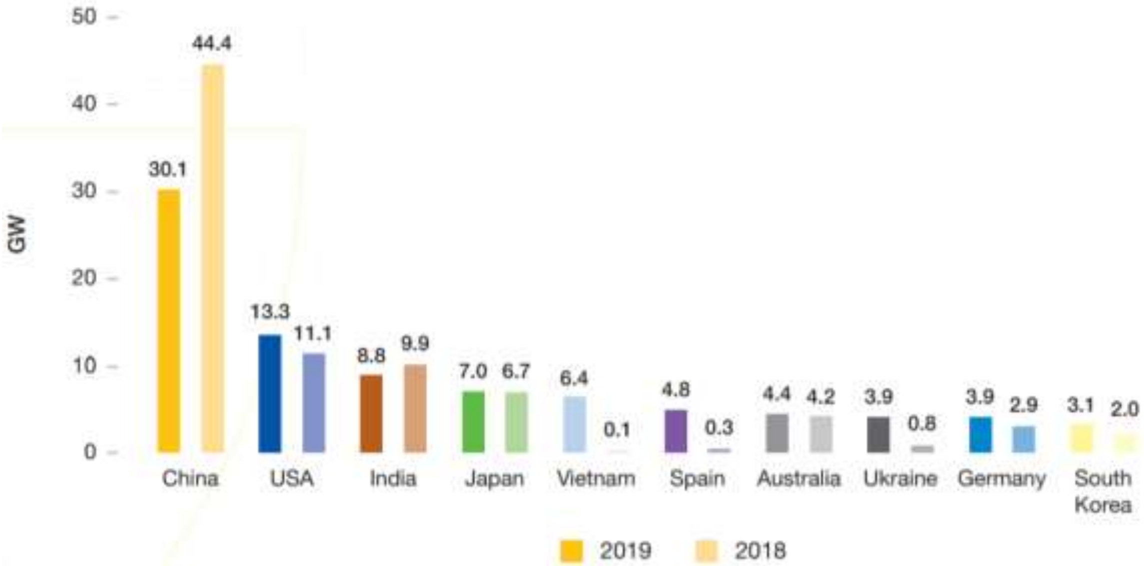
Based on the forecast by the JRC the material demand for the structural materials listed above could double by 2050 in in a Low Demand Scenario and increase by up to 21 times in the high demand one. The scenarios take into consideration power generation capacities, plant lifetimes, sub-technology market shares and material intensity.

Component manufacturing and integration

Overview: Solar PV market in the EU

Figure 5-13 below shows the ten countries worldwide with the biggest solar PV markets in 2018 and 2019. China is by far the biggest market, although it saw a large decrease between 2018 and 2019. In the EU, Spain and Germany are the two countries featured among the top ten. Table 5-2 lists the top five countries in the EU27 in terms of installed and cumulated solar PV capacity by 2019. As seen from the table, in 2019 Spain surpassed Germany in new solar photovoltaic installations, connecting almost 4 GW of capacity. The reason for the increase in capacity installations can be partly attributed to the Spanish government's new auctioning policy.[407]

Figure 5-13 Top 10 Solar PV markets in 2018-2019[408]



406 Ibid.

407 EurObserv'ER. (2020). Photovoltaic Barometer. Available at: https://www.eurobserv-er.org/category/all-photovoltaic-barometers/

408 SolarPower Europe. (2020). EU Market Outlook for Solar Power 2019-2023. Available at: https://www.solarpowereurope.org/eu-market-outlook-for-solar-power-2019-2023/

Table 5-2 Installed and cumulated solar PV capacity (estimation for off-grid includes) in the EU at the end of 2019 (MW)[409]

Country	2018 cumulated	2019 cumulated	2019 installed
Germany	45181.0	49016.0	3856.0
Italy	20107.6	20864.0	759.0
France	9617.0	10 575.9	965.5
Spain	5339.9	9232.8	3992.9
Netherlands	4522.0	6924.0	2402.0

Although manufacturing capacity has largely moved to Asia, European firms continue to maintain a strong presence in industry as can be seen in Figure 5-14. Especially, equipment manufacturing by companies such as Meyer Burger, Centrotherm and Schmid has a strong base in Europe. European companies are most competitive in the downstream activities of the value chain related to monitoring and control, balance of system and solar trackers. EU firms are also important players in systems development and operation worldwide.[410] Commercialization of new PV technologies and the momentum around the European Commission's Green Deal and COVID-19 recovery might offer an opportunity to rebuild the domestic industry.[411] In this context, initiatives such as SolarPower Europe's Solar Manufacturing Accelerator play an important role in supporting the deployment of solar PV manufacturing projects in Europe.[412]

Furthermore, the already existing research and innovation knowledge and capabilities based on centres like the CEA-Ines and Franhoufer ISE are an important asset. The European knowledge on solar PV has attracted companies such as the South Korean manufacturing company Hanwha Q Cells to establish research centres in Europe[413].

[409] EurObserv'ER. (2020). Photovoltaic Barometer. Available at: https://www.eurobserv-er.org/category/all-photovoltaic-barometers/
[410] European Commission. (2020). Commission Staff Working Document Clean Energy Transition – Technologies and Innovations – Part 2. Reproduced from ASSET Study
[411] Euractiv. (2020). Solar's unique opportunity to lead the reindustrialisation of Europe. Available at: https://www.euractiv.com/section/energy/opinion/solars-unique-opportunity-to-lead-the-re-industrialisation-of-europe/
[412] SolarPower Europe (2020). Accelerating the deployment of Solar PV manufacturing projects in Europe. Available at: https://www.solarpowereurope.org/campaigns/manufacturing-accelerator/
[413] Headquarter for Technology and Innovation based in Bitterfeld-Wolfen, Germany. See: https://www.q-cells.eu/about-q-cells/about-hanwha-q-cells/our-locations.html

Figure 5-14 European players across the PV Industry Value Chain[414]

	Equipment for PV manufacturing	Solar PV panels (Silicon, Cells, Modules)	Monitoring & Controls	Balance of system	EPC	Deployment
Key activities	• PV manufacturing equipment • New PV technology development	• Manufacturing of silicon ingots, cells and PV modules	• Developing hardware and software to improve the performance of solar farm	• All non-module hardware (Inverters, Trackers, Steel structures, cabling, etc.)	• Engineering design • Construction • Lease & Insurance • Commissioning	• Development • Finance • O&M
Market Size (M€)	Global 1.329 EU 86	Global 57.842 EU 7.368	Global 2.694 EU 678	Global 25.707 EU 3.275	Global 17.995 EU 2.292	Global 26.993 EU 3.438
Market Growth Outlook	EU: Global: R&D directed to HJT	EU: Global: Focus on increasing cell efficiency	EU: Global: Focus diagnostics and optimisation	EU: Global: Increasing warranties and cost reduction	EU: Global: Focus on factory vs field work	EU: Global: Access to low cost capital and leading technology is key
Key players EU	• Valoe • Centrotherm • SCHMID	• Hanwha Q-cells (Partially EU) • Wacker Chemie • 3Sun	• GreenPower Monitoring • AlsoEnergy (partially EU) • Solar-log • Meteo&Control	Inverters • SMA Trackers • Soltec	Highly fragmented market dominated by local players	• Enel Green Power • Engie • BayWa.re
Key players Rest of the World	• Meyer Burger	• Trina Solar • Jinko Solar • GCL-Si • Hanwha Q-cells (Partially KR) • JA Solar • Longi • Tongwei	• AlsoEnergy (Partially US) • Inaccess	Inverters • Huawei • SunGrow Trackers • Nextracker • Array Tech	Highly fragmented market dominated by local players	• Nexterra • BP Lightsource
Critical materials	None	Silver, Copper	None	None	None	None

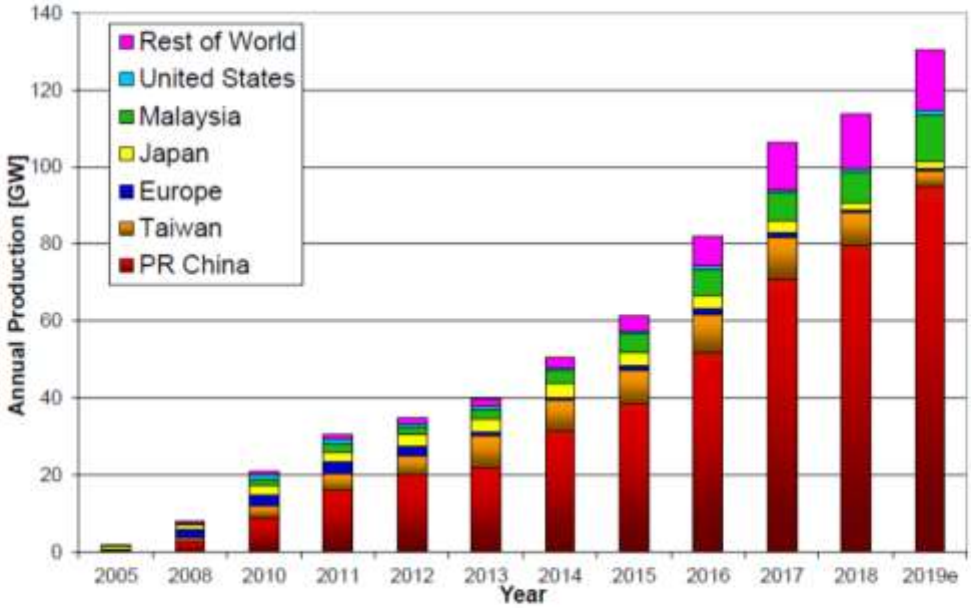
Legend: (10 year CAGR) >15% >10% >5% >0%

PV cells and modules

Previous results from the study on energy technology dependency indicated that potential vulnerable elements mainly relate to the production of PV cells, modules and inverters.[415] While there are some equipment manufacturers in Europe, and especially Germany, that still supply machinery and equipment to produce highly efficient solar cells and modules, the production of cells and modules has almost entirely migrated to Asia. The EU has a slightly stronger position in module manufacturing and hence a lower external dependence.[416] Figure 5-15 below illustrates the share of European PV cell/module production from 2005 to 2019 relative to the rest of the world. Based on interview reports from a previous study, it was reported that whereas EU-based manufactures have mixed opinions, EU-based installers do not consider reliance on non-EU suppliers to be a major risk given that the cell and module manufacturing market is highly competitive with sufficient suppliers to choose from.[417] In spite of these sentiments, the limited manufacturing capabilities within the EU do impart a vulnerability to the solar PV supply chain and should be monitored and addressed through support for developing manufacturing capabilities within Europe.

[414] European Commission. (2020). Commission Staff Working Document Clean Energy Transition – Technologies and Innovations – Part 2. Reproduced from ASSET Study.
[415] European Commission. (2018). Study on energy technology dependence: Detailed assessment on dependencies within the wind energy, solar PV and battery energy storage value chain (Task 4)
[416] Ibid.
[417] Ibid.

Figure 5-15 World PV cell/module production from 2005 to 2019 (estimate)[418]



Inverters

The main function of PV inverters is to convert direct current (DC) power to alternating current (AC) power. EU manufacturers are net exporters of inverters.[419] Companies such as SMA, Fronius, FIMER/ABB, Ingeteam and Power Electronics all manufacture inverters in the EU. The inverter industry was highly concentrated, with production in the top four countries comprising 78.0% of the global total in 2017. However, with one of the top four producers headquartered in Germany and one headquartered in Switzerland (a party to the Schengen Agreement) and with European countries (including Switzerland) accounting for 27% of the total global market in 2017, the observed concentration is currently not considered a threaten Europe's energy supply or renewables deployment.[420]

Evidence of vulnerability to the COVID-19 pandemic

Given that China is the biggest manufacturer of solar PV equipment and that Jiangsu province, which is responsible for ~ 60% of the solar production capacity in the country, was strongly hit, the global solar PV supply chain was also affected.[421] SolarPower reports several disruptions to the global solar PV supply chain mostly due to component manufacturers and other suppliers and increased logistics problems. In Europe, Italy experienced severe problem; according to the association Italia Solare, one in five solar companies said they were at risk of being pushed out of business and about one quarter were considering cuts to the workforce.

[418] Jäger-Waldau, A. (2019). PV Status Report 2019. EUR 29938 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-12608-9, doi:10.2760/326629, JRC118058
[419] European Commission. (2019). Study on energy technology dependence: Detailed assessment on dependencies within the wind energy, solar PV and battery energy storage value chain (Task 4). Available at: https://op.europa.eu/en/publication-detail/-/publication/4d794ddb-5391-11ea-aece-01aa75ed71a1/language-en
[420] Ibid.
[421] PowerTechnology. (2020). Coronavirous outbreak expected to hit the global solar supply chain. Available at: https://www.power-technology.com/comment/coronavirus-outbreak-global-solar-supply-chain/

5.3. Hydropower & pumped hydro storage

Introduction and technology description

According to the study on "Hydropower Technologies: The State of the Art" (Hydropower Europe, 2020[422]), hydropower generation corresponds to about 12% of the European net electricity generation and 36% of electricity from renewable resources in Europe (EUROSTAT, 2019).
In 2019, approximately 151.4 GW of hydropower capacity was installed in the EU27 (against 1 308 GW globally, according to IHA's Hydropower Status Report[423], from 1 025GW in 2010[424]).
Hydropower is technically mature. With about 60 to 70% of the economically feasible hydropower potential used so far within Europe, there is still an untapped potential, which allows hydropower to perform this role.[425]

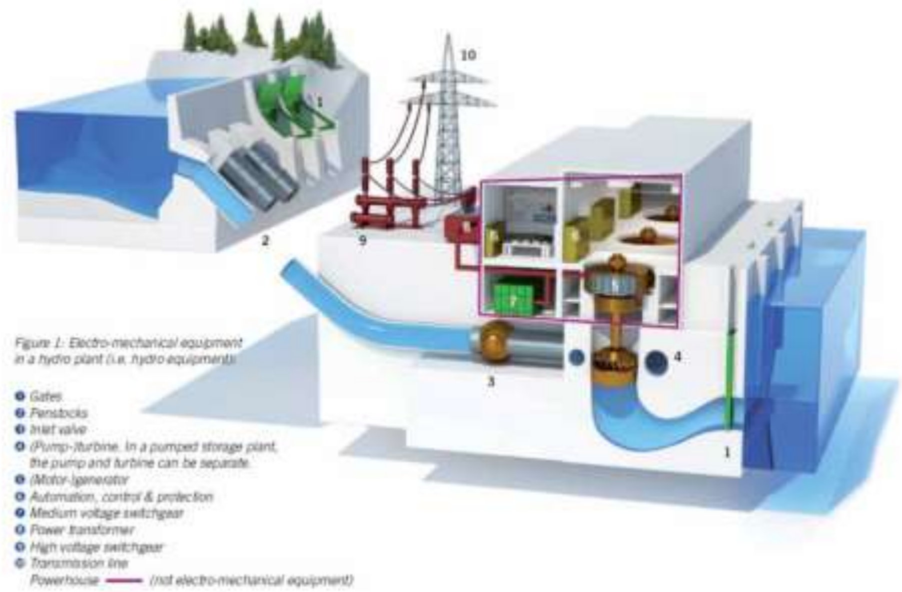
Hydropower is a controllable (or dispatchable) renewable energy source. This is in part due to control over the source through its storage capabilities, and the greater predictability of its generation in comparison to wind and solar power. Hydropower is, however, variable over longer time scales, as it depends on precipitation and water run-off. At a regional level, climate change may affect the potential for power generation (even if there is no clear pattern across Europe), but at the same time its role in water management using reservoirs can contribute to mitigating negative effects in term of water availability.

Over the past decades, hydropower equipment has been optimized to achieve high performance, availability and flexibility. Regarding hydropower infrastructure, innovative measures to mitigate environmental impacts have been developed. Moreover, significant improvements have been enabled by computer technologies in many areas, including design, construction, monitoring, diagnostics, protection and control. Investment into research and development (R&D) is fundamental to meet advances in technology and to deal with market competition.

Hydropower is based on a basic physical concept. Hydropower plants convert the potential or gravitational energy of water first into mechanical and then into electrical energy: the flow of water turns a turbine, which is connected to a generator. While the design changes according to local conditions, the main components highlighted in Figure 5-16 are the basic elements of conventional hydropower plants.

[422] Hydropwer Europe. (2020). Hydropower Technologies: The State-of-the-Art. Available at: https://hydropower-europe.eu/private/Modules/Tools/EUProject/documents/2/WP4_DIRp_02_D4_3_StatusHydroTech_v4_2_Final.pdf
[423] International Hydropower Association. 2020 Hydropower Status Report. Available here: https://www.hydropower.org/publications/2020-hydropower-status-report
[424] IRENA. (2020). Renewable Power Generation Costs in 2019. Available at: https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019
[425] Hydropower Europe. (n.d.). Vision of the HYDROPOWER EUROPE Forum. Available at: https://hydropower-europe.eu/about-hydropower-europe/vision-of-the-forum/

Figure 5-16 Electro-mechanical equipment in a hydro plant[426]



Hydropower includes stations operating with large water quantities stored in artificial reservoirs behind dams called storage power plants, run-of-river projects utilising the real-time natural flow of water bodies, and pumped hydropower storage (PHS). An additional type of systems is conduit hydropower that utilises the available energy in the conduit systems of e.g. water distribution, irrigation, and sewage networks.

In most of the countries in Europe 'mini hydro' is considered below 1 MW, 'small hydro' below 10 MW and 'large hydro' above 10 MW.

Different types of turbine have been developed, such as Pelton, Francis and Kaplan to mention the most commonly used, in order to have the highest efficiency in power generation for different ranges of head and flow.

Pumped-storage hydropower plants operate with two reservoirs - a lower and an upper one. The two reservoirs are connected to each other through pressure tunnels and shafts or penstocks. A pumped-storage plant moves water between the two reservoirs. In production mode, the plant operates like a conventional hydroelectric plant: water is released from the upper reservoir through the turbines to generate electricity. In pumping mode, electrical energy from the grid is used to pump the water from the lower reservoir to the upper one. A motor–generator is used to work either as a generator in the production mode or as a motor in the pumping mode. Therefore, components of the supply chain are more or less the same.

The supply chain of hydropower plant

The hydropower and pumped hydro storage value chain can be separated into the stages shown in Figure 5-18. Generally, in the literature, no specific research has been conducted to identify vulnerable elements in the hydropower supply chain (raw materials, compounds block).

The selection of the vulnerable elements is based on the assessment of the following criteria, but also on the literature review and stakeholder consultation.

[426] Hydropwer Europe. (2020). Hydropower Technologies: The State-of-the-Art. Available at: https://hydropower-europe.eu/private/Modules/Tools/EUProject/documents/2/WP4_DIRp_02_D4_3_StatusHydroTech_v4_2_Final.pdf

Figure 5-17 Vulnerabilities in the hydropower and pumped hydro storage supply chain

Supply chain component	Vulnerable element	Import dependency	Market concentration	Easy of substitutability	Price stability
		Import share - Number of importers/sources	Number of manufacturers/suppliers	Based on evidence from stakeholder interviews	Coefficient of variation
Raw / processed materials	Aluminium	59%	43% (RU, DE, MZ, FR)	Medium, by copper	22%
	Cement	IR ~0-5%			
	Copper	44%	58% (PL, CL, PE, ES)	Medium, by aluminium	42%
	Steel	21%	44% (Extra-EU) (RU, TR, CN, UK)		21%
	Composite materials (e.g. fibre-reinforced composites or FRC)				
Components / Equipment / Assembly	Hydraulic turbines and water wheels	mainly exporting	2 MSs on global top 7		
	Parts for hydraulic turbines and water wheels	mainly exporting	2 MSs on global top 7		

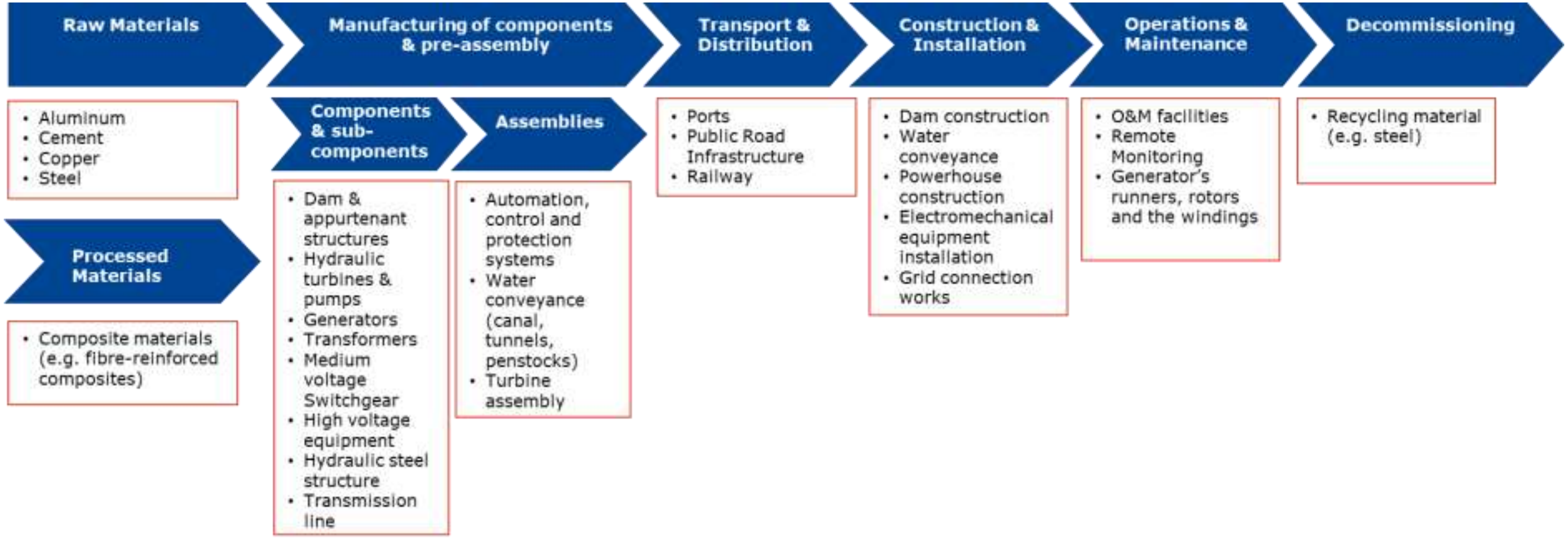
Notes: CR4 – concentration ratio of 4 largest suppliers. Extra-EU – CR only for third country suppliers.

Sources: Eurostat PRODCOM/COMEXT; JRC. (2020). Study on the EU's list of Critical Raw Materials; other sources listed in section.

None of the elements appear to be vulnerable according to the assessment of these criteria, and both the literature and the stakeholders lead to the same conclusion. However, these criteria should only be considered as a preliminary assessment of the vulnerability of the elements, which is refined with other information sources.

Figure 5-18 illustrates the hydropower value chain.

Figure 5-18 The supply chain of hydropower and pumped hydro storage



Based on the analysis of the supply elements, none of the elements were identified as highly vulnerable. More detailed information is provided below:

Raw Materials and Compounds

Hydropower uses materials such as steel, concrete (cement), and copper, which are available in most parts of the world. Concrete is used for dam construction and the required civil works including the power station building. In large-scale stations, concrete may also be used in the construction of tunnels and caverns. According to the report on progress of clean energy competitiveness (COM(2020) 953[427]), almost half of the installation cost (45% on average) of a hydro project relates to civil works. Hydropower stations are location-specific and each project has unique design characteristics. Accordingly, in regions where the best locations have already been developed such as the EU, the remaining technical potential usually refers to less advantageous sites and involves higher installation costs.

Hydropower dam development involves excavation and tunnelling, leading to the significant use of energy and explosives. Like for any civil works, some quantities of timber, aluminium, plastics are required.

The manufacture of mechanical components for hydropower typically uses steel. The industry has optimized the production processes of hydraulic machinery with steel because of its mechanical strength and resistance to corrosion. For large units, steel will likely remain the material of choice, while composite materials such as fibre-reinforced composites can be used to save weight and reduce manufacturing cost and environmental impact, especially for the rising small (below 10 MW) to micro-sized (below 100 kW) turbines.[428]

Copper is used at relatively lower quantities in the generator sets.

In terms of O&M, steel and copper is required for the replacement of runners, rotors and the windings of the generator, respectively.

Component manufacturing and integration

The market performance of hydropower is usually connected to trade of hydropower turbines for large-scale projects. A large number of turbine manufacturers exists in the EU27 and globally[429], the majority of which focuses exclusively on small-scale turbines. The market of large-scale units –above 10 MW– is dominated by a rather small number of companies.

In monetary terms, investments in large turbines represent a very large share of the global hydropower market. Besides, the small-scale market is not systematically monitored. Therefore, this assessment focuses exclusively on the global market of large turbines. An additional particularity of the hydropower market is that a significant part of investments is not monitored as it refers to the civil works and the associated consultancy services.

The two main categories of goods associated with hydropower technology in the PRODCOM[430] (Eurostat data on "sold production, exports and imports") are: "hydraulic turbines and water wheels" (PRODCOM code 28112200) and "parts for hydraulic turbines and water wheels" (28113200).

Overall, in 2019, the EU27 exported hydropower parts and turbines with a total value of 322 million EUR and 99 million EUR, respectively. The same year, the cumulative EU27 imports accounted for 142 million EUR. Imports refer mainly to parts for countries that are important exporters, indicating the presence of a processing market that uses parts to manufacture components or systems that can be exported.

The worldwide leading hydro turbines and generators (HT&G) manufacturing companies are Dongfang (CN), Harbin Electrics (CN), Voith (DE), GE (USA), Andritz (AT), Toshiba (JP), Zhe Fu (CN), PR Mach (CN) and Bharat Heavy Electricals Limited (IN). The market share for the 2013-2017 period

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[427] European Commission. (2020). Progress on clean energy competitiveness. Available at: https://ec.europa.eu/energy/sites/ener/files/report_on_clean_energy_competitiveness_com_2020_953.pdf

[428] Hydro Review. (2015). How composite materials can be used for small hydro turbines. Available at: https://www.hydroreview.com/2015/03/10/how-composite-materials-can-be-used-for-small-hydro-turbines/#gref

[429] Energy Xprt. (n.d.). Hydropower Turbines Companies (Hydro Energy). Available at: https://www.energy-xprt.com/hydro-energy/hydropower-turbines/companies

[430] Eurostat. (2019). Prodcom List 2019. Available at: https://www.ine.es/en/daco/daco42/encindpr/lista_prodcom_en.pdf

(in Mwe) was led worldwide by Asian companies (45.9% for China, 0.7% India and 1.6% Japan), then by European companies with 32.4%, and by America with 17.2%. The catalyst for the strong HT&G market during this period (2013-2017) was China representing about 58.7% of the total installed capacity, followed by India (4.4%), Brazil (4.2%), Ethiopia (3.2%) and Laos (2.8%). Outside China, the EU-based companies delivered 56.2% of the total orders in terms of capacity (2013-2017).[431]

With a share of 32.4% on the Chinese market & 56.2% on the market outside China, EU manufacturers can be considered having a leading role and being global leaders. EU27 investments in hydropower have been limited in the recent past. Between 2010 and 2019, only 8.3 GW of new power capacity has been installed in the EU27 with a compound annual growth rate (CAGR) equal to 0.56%, while the global CAGR over the same period was 2.47% showing the much greater investments in hydropower outside the EU (china alone installed ~64GW over the 2013-2017 period).

According to an analysis of emerging technologies in the hydropower sector (Kougias, 2019[432]), the production of patents (using the relevant Y code families of the Coordinated Patent Classification (CPC) for climate change) shows China to be by far the most active country in hydro R&D (number of inventions >3 000)[433], while the total number of inventions reaches ~460 in the EU27 on the 2010-2016 period (with and average annual number of inventions a little bit above 60).

Evidence of short-term vulnerability to the COVID-19 pandemic

According to EURELECTRIC's Impact of COVID-19 on the electricity value chain - Insights from the European power sector, the COVID-19 crisis had no to minor disturbance for operation for now. Only refurbishments were delayed in several countries (AT, PT, SE).

The main conclusion of Eurelectric's assessment are

- In general procedures in place for minimization of staff onsite/safety rules;
- No to minor disturbance for maintenance operations for now. In PT they have been stopped;
- Refurbishments have been either stopped (major ones postponed to next dry season in PT) or faced delays (AT, SE) and reorganization due to safety measures for employees (AT, LV). In PL refurbishment is continuing but procurement of construction/renovation has been stopped by local governments. For SE unclear if these delays could become critical.
- PT signals problems on equipment suppliers' side including layoffs.

[431] McCoy power reports. (2018). Hydro Turbines and generators 12M'17 Report. Available online at: https://www.mccoypower.net/products
[432] Kougias I et al.(2019). Analysis of emerging technologies in the hydropower sector. Renewable and Sustainable Energy Reviews. 113, 109257. https://doi.org/10.1016/j.rser.2019.109257
[433] Partially also due to the different patenting procedure in the country.

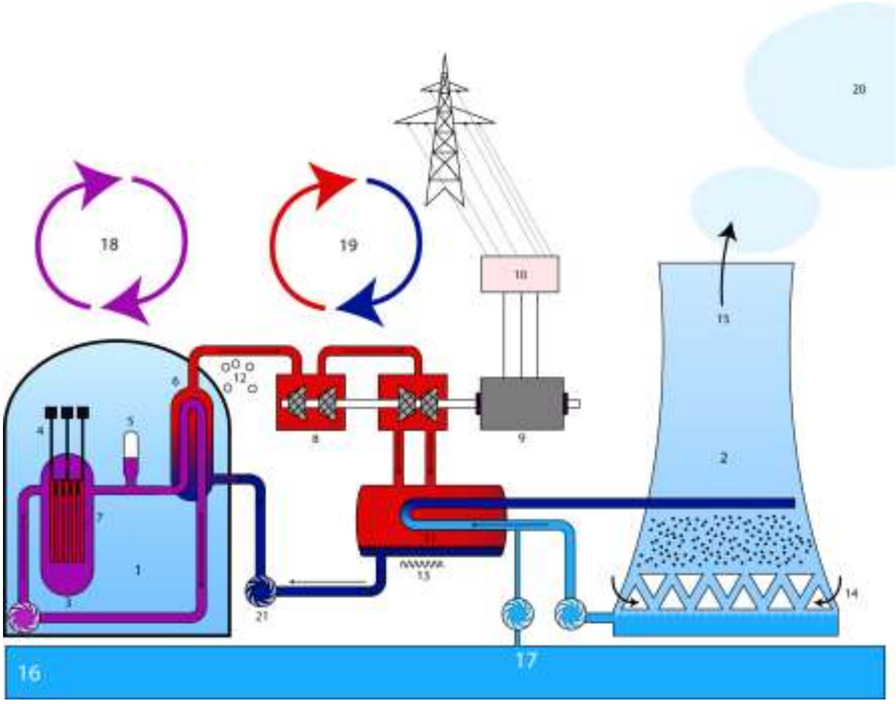
5.4. Nuclear fission

Introduction and technology description

Fission nuclear energy is a mature electricity generation technology based on the production of steam from the heat released by the fission of atoms (usually uranium and plutonium) to power steam turbines. There are also projects in the EU exploring possibilities for the co-generation of electricity and heat using nuclear energy. Experience with the provision of district heating via nuclear exists in CZ, RO, HU, SK (and CH as a third country), and nuclear is also employed for providing process heat for the paper and pulp industry.[434]

Figure 5-19 below presents the main components of a pressurized water reactor (PWR), the most common reactor in operation in the EU and worldwide. The reactor, fuel handling, safeguard and nuclear auxiliary, and operations buildings form the main parts of the nuclear 'island'. In addition, there are the turbine and diesel generator buildings, which needs to meet less stringent safety standards than the nuclear island.[435] However, the categorization of buildings may vary depending on the literature source. The main components of a PWR include the reactor pressure vessel, the steam generator, pressuriser, piping systems, reactor coolant pumps, the cooling tower, and the fuel elements and control rods.

Figure 5-19 Design of a nuclear power plant with pressurized water reactor[436]



1. Reactor containment building
2. Cooling tower
3. Reactor pressure vessel
4. Control rods
5. Pressuriser
6. Steam generator
7. Fuel elements
8. Turbine
9. Generator
10. Transformer
11. Condenser
12. Gaseous
13. Liquid
14. Air
15. Air (humid)
16. River
17. Cooling-water circulation
18. Primary circuit
19. Secondary circuit
20. Water vapor
21. Pump

Thirteen out of the 27 EU Member States have nuclear power plants (NPPs), which provide around a quarter of the electricity produced in the EU. EU Member States have the freedom to determine their energy supply mix, including via the use of nuclear energy.[437] The 106 nuclear power reactors operational in 13 Member States of the EU27 had, in February 2021, a capacity of 104 GW_e.[438] As of February 2021, three Member States had four reactors under construction (FI, FR and SK), five had reactors planned (BG, CZ, FI, HU and RO) and seven had proposed reactors (BG, CZ, FR, PL, RO, SK and SI).[439]

[434] For example the European Nuclear Cogeneration Industrial Initiative (NC2I); IEA. (2020). European Union – Energy Policy Review; JRC. (2012). Study on the state of play of energy efficiency of heat and electricity production technologies.
[435] Fit for Nuclear. (2015). Are you fit for nuclear? Available at: https://www.businesslincolnshire.com/media/1609/fit4nuclearpresentationjune15.pdf
[436] Source: Wikimedia Commons. No changes made. Creative Commons Attribution-Share Alike 2.0 Germany license.
[437] European Parliament. (2020). Nuclear energy factsheet. Available at: https://www.europarl.europa.eu/factsheets/en/sheet/62/nuclear-energy
[438] International Atomic Energy Agency. (2020). The Database on Nuclear Power Reactors. Available at: https://www.iaea.org/resources/databases/power-reactor-information-system-pris
[439] World Nuclear Association. (2020). Nuclear Power in the European Union. Available at: https://www.world-nuclear.org/information-library/country-profiles/others/european-union.aspx.

The Long-Term Strategy of the European Commission ('A Clean Planet for All') notes a number of challenges for nuclear energy, namely "high construction costs (also linked to strict safety regulations), public acceptance issues in some Member States (demonstrated also in the results of the public consultation) and increasing competitiveness of other energy sources", as well as uncertain electricity market prices.[440] Nonetheless, the strategy envisages that by 2050 nuclear energy will provide 15% power share, to complement the over 80% electricity to be produced from renewable sources. This will represent the backbone of the future carbon-free European power system. The European Commission indicates that nuclear experts across Europe expect nonetheless cost reductions in the future, with an aim of a reduction of 30-35% by 2030 compared to the present. Reducing the cost of nuclear energy involves the "development of non-electric applications, the development of innovative fuels and the development of smaller reactors".[441] The global nuclear energy installed capacity is expected to grow by 2050, driven especially by China, with investments totalling up to 3 trillion EUR worldwide. In the EU, as around 90% of the existing nuclear electricity production capacity will need to be shut down or replaced by 2050, Member States will need to make choices regarding the replacement of their NPP fleet. Germany and Belgium have decided to phase out their current NPPs, while France plans to reduce the share of nuclear energy in its electricity mix. From 2030 on, the commissioning of new NPPs in the EU would reverse this decreasing trend and increase slightly the total installed capacity. Multiple EU Member States and operators have expressed their desire to extend the operation of their NPPs beyond the originally planned long-term operation[442] and this is already happening in a significant number of EU Member States with operating NPPs. The Commission estimates that maintaining a generation capacity in the EU between 95 and 105 GWe until 2050 would require between 350 and 450 billion EUR in new investments, to replace nuclear power plants due to be decommissioned.

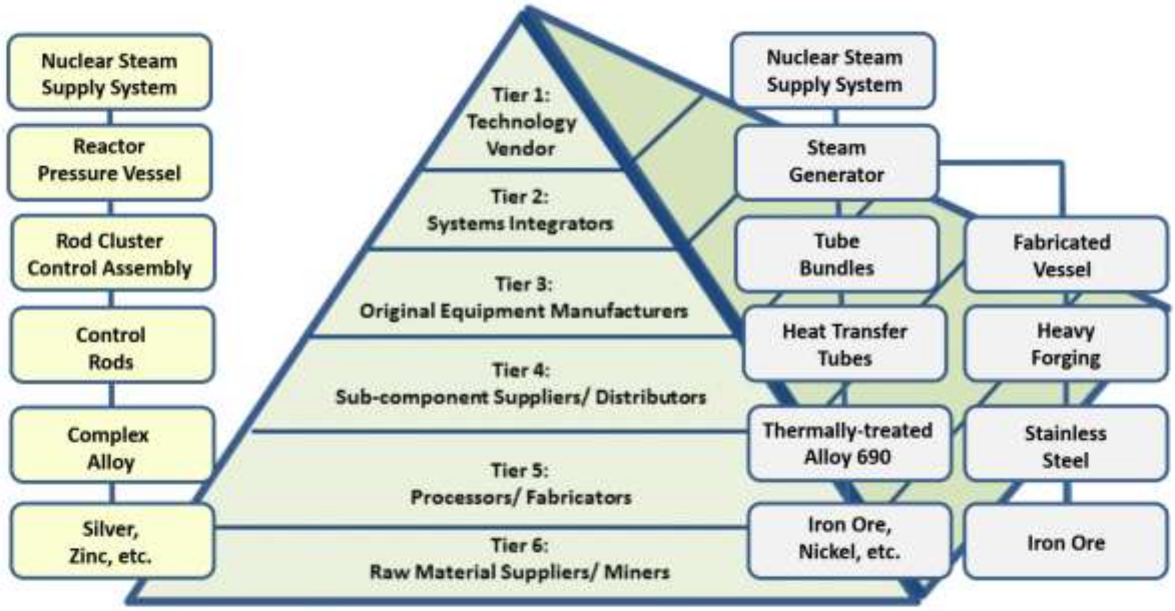
The supply chain of nuclear energy

Figure 5-20 presents the different tiers in the nuclear energy supply chain as well as the main components sourced for a nuclear reactor, with a "technology vendor" being the main contractor. While in the past NPPs were manufactured mostly by national vertically-integrated companies, the current market for new build and replacement structures, systems and component (SSCs) is much more international, with various international vendors competing for projects, which nonetheless have to meet national content requirements.[443]

Simultaneously, the world nuclear supply chain is facing a number of challenges: "shortage of skilled suppliers and contractors, the shrinking of manufacturing bases in established nuclear countries, increased supply chain length, shortened product life cycles, emerging new materials, advances in information technology, new technological processes and standards and the globalization of supply sources".[444] To be able to extend the long-term operation of existing nuclear power plants and commission new ones, the EU itself needs to "maintain its competence, technology, and ability to build new facilities, along with the associated supply chain". [445]

[440] European Commission. (2018). In-depth Analysis in Support of the Commission Communication COM(2018) 773 A Clean Planet for All. Available at: https://knowledge4policy.ec.europa.eu/publication/depth-analysis-support-com2018-773-clean-planet-all-european-strategic-long-term-vision_en
[441] European Commission. (2020). SWD(2020) 953. Clean Energy Transition – Technologies and Innovations.
[442] European Commission. (2017). Nuclear Illustrative Programme. Available at: https://ec.europa.eu/transparency/documents-register/detail?ref=COM(2017)237&lang=en
[443] World Nuclear Association. (2020). Heavy Manufacturing of Power Plants. https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/heavy-manufacturing-of-power-plants.aspx ; complemented with National Energy and Climate Plans.
[444] International Atomic Energy Agency. (2019). Nuclear Operators' Forum Focuses on Sustainable Management of the Nuclear Supply Chain. Available at: https://www.iaea.org/newscenter/news/nuclear-operators-forum-focuses-on-sustainable-management-of-the-nuclear-supply-chain
[445] IEA. (2020). European Union – Energy Policy Review. Available at: https://www.iea.org/reports/european-union-2020

Figure 5-20 Nuclear supply chain[446]



A high number of components need to satisfy nuclear-grade safety quality levels or 'supplemental quality' levels which go above commonly used industrial quality standards. The Nuclear Energy Institute supply chain map lists tens of components which need to comply with these enhanced safety levels. Most components requiring a nuclear quality standard are located in the nuclear 'island', while those in the turbine island mostly only meet industrial quality standards.[447]

Suppliers to the nuclear industry are required to maintain a nuclear-specific quality assurance programme for the SSCs and services that they wish to provide. This involves the need to obtain and maintain certificates according to standards specific to the nuclear industry. This increases the cost for provision of products and services, and reduces the number of qualified suppliers as suppliers are only willing to obtain and maintain certificates if there is some certainty of a stable demand for their products and services.[448]

An analysis of supply chain elements (summarised in Figure 5-20) was conducted to identify potentially vulnerable elements. The selection of the highly vulnerable elements is based on the assessment presented in the figure, but also on the literature review and stakeholder consultation. Some elements may appear to be highly vulnerable according to the assessment of these criteria, but for several other reasons (e.g. limited amount needed), both the literature and the stakeholders do not lead to the conclusion they should be considered as such. Therefore, the assessment of the criteria (Figure 5-21) should only be considered as a partial assessment of the vulnerability of the elements.

Considering this, the following elements are identified as vulnerable: several nuclear-grade certified suppliers (components/services for the nuclear island) and services given by certified providers. Vulnerable elements are highlighted in bold in Figure 5-22, which presents an overview of the nuclear fission supply chain.

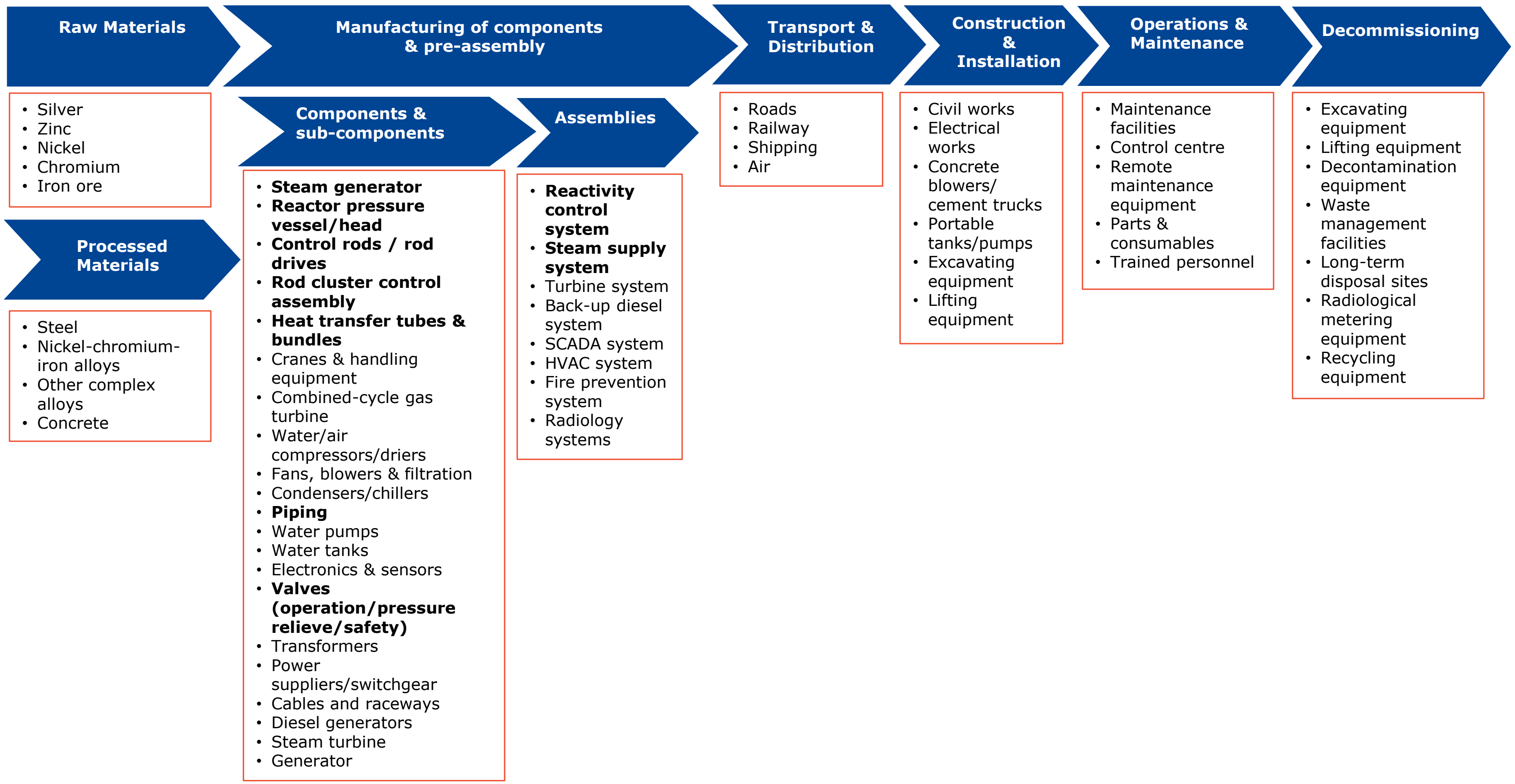
[446] Kaser, G. (2014). The World Nuclear Supply Chain – an Overview. Available at: https://www.oecd-nea.org/upload/docs/application/pdf/2020-07/wpne_workshop_2._1_the_world_nuclear_supply_chain_an_overview.pdf
[447] Nuclear Energy Institute. (2010). Supply Chain Map – Nuclear Reactor Components.
[448] Deloitte for FORATOM. (2019). Economic and Social Impact Report. Available at: https://www.foratom.org/press-release/investing-in-low-carbon-nuclear-generates-jobs-and-economic-growth-in-europe/

Figure 5-21 Nuclear fission supply chain elements vulnerability

	Supply chain stage	Vulnerable element	Import dependency	Know-how/specialisation	Market concentration	Easy of substitutability	Price stability
			Import reliance	Patents share / other	CR4 / Main suppliers	Qualitative analysis	Coefficient of variation - 20 years
Nuclear fission	**Raw materials**	**Silver**	40%	NA	54% (MX, PE, CN, AU)	NA	54%
		Iron ore	72%	NA	71% (AU, BR, CN, IN)	NA	68%
		Zinc	60%	NA	64% (CN, AU, PE, US)	For corrosion protection Zi coating is substituted by Al alloys (less effective), Cd, paint and plastic coatings (less durable)	40%
		Nickel	59%	NA	59% (CN, RU, JP, CA)	Medium	50%
		Chromium	66%	NA	88% (CN, ZA, KZ, IN)	Low	NA
	Processed materials	**Steel**	21%	NA	44% (Extra-EU) (RU, TR, CN, UK)	NA	12%
		Concrete	~0-5%	NA	NA	NA	NA
		Nickel alloys	>90%	NA	>90% (US, UK, JP, CN)	NA	NA
	Components / Equipment / Assembly	**Reactor vessels**	Major EU large forge presses	NA	NA	Low	NA
		Reactor parts	51%	Limited patenting and reduced R&D funding	100% (Extra-EU) (CN, US, JP, RU)	Difficulties in supplier certification	NA

Notes: CR4 – concentration ratio of 4 largest suppliers.
Sources: Eurostat PRODCOM/COMEXT; JRC. (2020). Study on the EU's list of Critical Raw Materials; other sources listed in section.

Figure 5-22 Analysed supply chain of nuclear fission[449]



*** Overall vulnerability in supply chain due to limited number of certified suppliers for high safety class components in nuclear island.**

Note: critical dependencies found highlighted in ***bold***

[449] Kumara et al. (2020). Electrical Characterization of a New Crosslinked Copolymer Blend for DC Cable Insulation.

The analysis of elements of the nuclear fission supply chain, in particular vulnerable elements highlighted in bold in Figure 5-22, is detailed below.

Raw and processed materials

The most critical material for the EU nuclear industry is uranium, as it is the primary fuel for the NPPs.[450] However, the fuel supply chain is out of scope of this study.

The manufacturing of the structures, systems and components of a NPP require a large number of raw and processed materials. The most relevant raw materials comprise silver, zinc, nickel, chromium and iron, while processed materials include steel, complex alloys such as alloy 690 (a chromium-nickel-iron alloy), and concrete. A generation III nuclear power plant uses 6 000 m^3 of concrete, 61 000 t of steel and 4 000 t of steel forgings.[451]

The EU is highly reliant on imports for a number of raw and processed materials, with an import reliance ratio of around or over 60% for iron ore, zinc, nickel, chromium and nickel alloys. Moreover, for all these materials the foreign supply market is highly concentrated, with again the CR4 ratio being of around or over 60%. There are no or low dependency concerns for steel and concrete, as well as for nickel alloys, as the German VDM metals is a leading manufacturer of alloy 690 (together with the US-based Special Metals Corporation).

Components manufacturing and integration

Major international nuclear energy technology vendors include Framatome (FR), Candu Energy (CA, a subsidiary of SNC-Lavalin), Rosatom (RU) Westinghouse (US), GE Hitachi (US/JP), Mitsubishi Heavy Industries (JP), Toshiba (JP), Doosan (KR), KEPCO (KR), SNPTC (CN), CNNC (CN), CGN (CN) and NPCIL (IN).[452] Particularly, CGN, or the China General Nuclear Power Group, is the largest constructor of NPPs worldwide.[453]

Some of these companies have filed for bankruptcy in recent years - such as Westinghouse, which is still active in the nuclear reactor market. In other cases, these technology vendors have pulled out of specific NPPs projects, e.g. in the UK.[454] This can lead to delays in the commissioning of nuclear power plants and even require the switch to other suppliers/technology vendors.

The main EU nuclear technology vendor, Framatome (FR), indicates that through its global supply chain it is able to provide "50% of safety classified and auxiliary equipment + instrumentation and control (operational, safety and non-computerized)", with the remainder being sourced internationally. [455]

For very large modern nuclear reactors (Gen III+) forging of the reactor pressure vessel becomes an important supply chain bottleneck, as it requires large forging presses which are scarce worldwide and which can handle only a few vessels per year (together with orders from other industry sectors). The World Nuclear Association (WNA) indicates that in 2009 Westinghouse could source pressure vessel closure heads and complex steam generator parts only from JSW (JP), while Framatome had 'a little more choice'. [456]

Specifically, heavy forging capacity in operation is concentrated in Japan (JSW), China (China First Heavy Industries, China Erzhong, SEC), France (Le Creusot), and Russia (OMZ Izhora). Furthermore, "new capacity is being built by JSW and JCFC in Japan, Shanghai Electric Group (SEC) and subsidiaries in China, and in South Korea (Doosan), Czech Rep (Pilsen) and Russia (OMZ Izhora and ZiO-Podolsk). New capacity is planned in UK (Sheffield Forgemasters) and India (Larsen & Toubro, Bharat Heavy Electricals, Bharat Forge Ltd). In China the Harbin Boiler Co. and SEC subsidiary SENPE are increasing capacity." The US has no comparable forging capacity. Europe lists 8 heavy forging

[450] European Commission. (2020). SWD(2020) 953. Clean Energy Transition – Technologies and Innovations.
[451] Kaser, G. (2014). The World Nuclear Supply Chain – an Overview.
[452] Ibid.
[453] European Commission. (2020). SWD(2020) 953. Clean Energy Transition – Technologies and Innovations.
[454] For example Westinghouse filed for bankruptcy. See https://www.nytimes.com/2017/03/29/business/westinghouse-toshiba-nuclear-bankruptcy.html
Several planned UK NPPs were at risk after Toshiba closed a subsidiary and Hitachi pulled out. See https://www.theguardian.com/business/2019/jan/17/hitachi-set-to-scrap-16bn-nuclear-project-anglesey-wales
[455] International Framework for Nuclear Energy Cooperation. (2017). Global Supply Chain and Localization, Issues and Opportunities: A Conference on the Customer Dialogue – Summary Conference Report.
[456] World Nuclear Association. (2020). Heavy Manufacturing of Power Plants. Available at: https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/heavy-manufacturing-of-power-plants.aspx

presses, by Framatome (FR), Forgiatura (IT), Sheffield (UK), Pilsen Steel[457], Vitkovice and OMZ Skoda (CZ), Saarschmiede (DE), Societa della Fucine (IT), and ENSA (ES).[458]

The EU28 had a nuclear energy technology trade surplus in the 2000-2015 period, reaching a peak of 0.5 billion EUR in 2012, which fell to around 100 million EUR in 2015. After 2003 it had trade surplus with all world regions. France has the highest trade surplus with the rest of the world, while Germany has the highest balancing in intra-EU28 trade. In the 2012-2015 period major export destinations were the US, CN, UA, CH and RU, while major technology suppliers to the EU were the US, CN, JP, CH and RU. Trade with the US and China especially has grown in the 2012-2015 period.[459]

With the reduced construction rate for NPPs worldwide and in Europe especially, challenges also arise related to technical capability, i.e. the sufficient availability of qualified personnel to design, build and operate the plants, including the supply chain of SSCs and services. The age of the nuclear experts in the industry is increasing, with only around 15% of the experts below the age of 35 in 2018.[460] In 2012, around 50% of the nuclear experts were expected to retire by 2030.[461]

The sourcing of products and services is important not only for new-build reactors, but also for the maintenance or upgrade of existing operating units.[462] Framatome has, for example, finished in 2018 the upgrading of instrumentation and control systems in the Swedish Forsmark NPP.[463]

The availability of certified suppliers is also a global challenge. To illustrate this trend, the number of ASME (American Society of Mechanical Engineers) certificate holders is decreasing since 2012, although there is an increasing number of manufacturers in China[464] (ASME N certificates are not required for all nuclear suppliers). This can lead to a supply chain bottleneck for various components which are complex and/or of a high safety class.

The sourcing of products and services from the domestic industry for the development of new NPPs requires the active involvement of national governments, starting with a "comprehensive assessment of national competencies", followed by industry-related activities to building the competency gaps. The IAEA recommends a rate of domestic subcontractors from 20% to 40% of a new NPP build.[465]

The share of European countries in patenting related to nuclear energy among OECD countries has decreased continuously since the 60s, and Europe was overtaken as world leader in patenting in the 80s by South Korea, Japan and China. Total nuclear R&D spending in the OECD countries has decreased markedly since the Fukushima accident in 2011.[466] Nonetheless, there is in the EU an increasing trend in the last years. Overall European Union R&I spending in nuclear energy increased

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457 Pilsen Steel is insolvent since January 2019 and was bought in 2020 by the Max Eicher group. See https://eurometal.net/max-aicher-acquires-pilsen-steel/

458 World Nuclear Association. (2020). Heavy Manufacturing of Power Plants.

459 Pasimeni F. (2017). EU energy technology trade: Import and export. EUR 28652 EN. Luxembourg (Luxembourg): Publications Office of the European Union. JRC107048

460 Eriksen, B., Christiansen, B., Chenel Ramos, R., Van Kalleveen, A. and Hirte, B. (2019). Results of surveys of the Supply of and Demand for Nuclear Experts within the EU-28 Civil Nuclear Energy Sector, EUR 30014 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-14173-0, doi:10.2760/499847, JRC117806.

461 Roelofs F, Von Estorff U. (2013). Top-down workforce demand extrapolation from nuclear energy scenarios. EUR 26008. Luxembourg (Luxembourg): Publications Office of the European Union. JRC81666

462 World Nuclear Association. (2020). Launch of the World Nuclear Supply Chain: Outlook 2040 report. Available at: https://world-nuclear.org/our-association/publications/global-trends-reports/world-nuclear-supply-chain-outlook-2035.aspx#:~:text=The%20World%20Nuclear%20Supply%20Chain%3A%20Outlook%202040&text=The%20report%20offers%20an%20up,small%20modular%20reactors%20are%20analysed.

463 POWER Engineering. (2018). Framatome Completes I&C Upgrade at Swedish Nuclear Reactor. Available at: https://www.power-eng.com/2018/12/13/framatome-completes-i-c-upgrade-at-swedish-nuclear-reactor/#gref

464 World Nuclear Association. (2020). Launch of the World Nuclear Supply Chain: Outlook 2040 report. Available at: https://world-nuclear.org/our-association/publications/global-trends-reports/world-nuclear-supply-chain-outlook-2035.aspx#:~:text=The%20World%20Nuclear%20Supply%20Chain%3A%20Outlook%202040&text=The%20report%20offers%20an%20up,small%20modular%20reactors%20are%20analysed.

465 International Framework for Nuclear Energy Cooperation. (2017). Global Supply Chain and Localization, Issues and Opportunities: A Conference on the Customer Dialogue – Summary Conference Report. Available at: https://www.ifnec.org/ifnec/upload/docs/application/pdf/2018-12/2017_ifnec_the_summary_report_of_the_conference_global_supply_chain_and_localization_issues.pdf

466 Lovering, J., King, L., and Nordhaus, T. (2017). How to make nuclear innovative. Available at: https://s3.us-east-2.amazonaws.com/uploads.thebreakthrough.org/legacy/images/pdfs/How_to_Make_Nuclear_Innovative.pdf

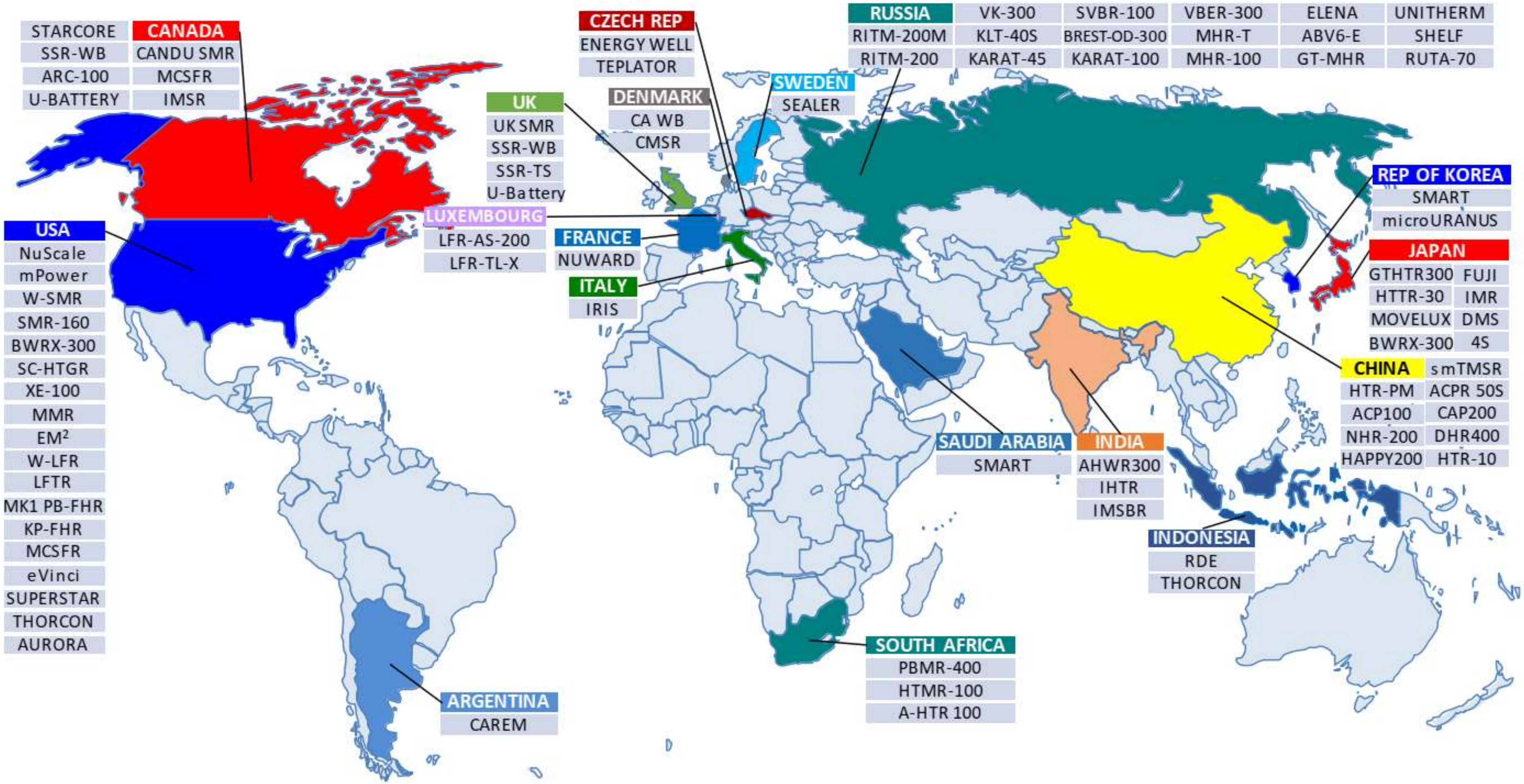
from 132.1 million € in 2014 to 227.6 million € in 2019 (estimated).[467] Public investments in the EU-28 in nuclear safety in 2016 were higher and amounted to 1 179 million EUR, while private investment amounted to 255 million EUR. Furthermore, the number of patents in nuclear safety in 2016 was 67.[468]

The EU is falling behind in R&D and investments on the main areas expected to lead to a reduction in the cost of nuclear energy: the use of nuclear-derived heat for industrial processes and district heating, the development of innovative fuels and of smaller reactors.[469]

Out of the 25 initiatives to develop land-based water cooled small modular reactors worldwide, three are from the EU (NUWARD, a French EDF consortium, and TEPLATOR, a Czech consortium, and IRIS, an international consortium led by Westinghouse but with current activities being undertaken by Italian organisations). Out of the initiatives to develop marine-based water cooled small modular reactors worldwide, none are from the EU. Most of these initiatives are based in Russia, China, the US or Japan. Of the 45 other initiatives addressing the remaining small reactor types (high-temperature gas cooled, fast neutron spectrum, molten salt, and micro-sized), only 4 are based in Europe (LFR-AS-200 and LFR-TL-X in Luxembourg, SEALER in Sweden, Waste Burner 0.2.5 in Denmark, and Energy Well in the Czech Republic).[470] This is illustrated in Figure 5-23.

[467] IEA. (2020). IEA Energy Technology RD&D Budgets. Available at: https://www.iea.org/data-and-statistics/data-product/energy-technology-rd-and-d-budget-database-2
[468] JRC. (2020). SETIS Research & Innovation data. Available at: https://setis.ec.europa.eu/publications/setis-reseach-and-innovation-data_en
[469] European Commission. (2020). SWD(2020) 953. Clean Energy Transition – Technologies and Innovations.
[470] IAEA. (2020). Advances in Small Modular Reactor Technology Developments- A Supplement to: IAEA Advanced Reactors Information System (ARIS) 2020 Edition. Available at: https://aris.iaea.org/Publications/SMR_Book_2020.pdf

Figure 5-23 Global Map of SMR Technology Development[471]



[471] Ibid, Annex I, P. 307.

Operation and maintenance

European operators of nuclear facilities are facing increasing challenges on their supply chain, such as obsolescence of safety-classified SSCs and difficulties in finding suppliers for these SSCs that are thus also willing to obtain the required certification. Suppliers are only willing to keep their nuclear QA programme or implement one if they expect regular order in sufficient quantities in the future.[472] This is a concern shared generally by the operators in EU Member States which have nuclear facilities. Procuring new SSCs to replace obsolescent ones may require a long and costly certification process, or old standards may be employed, sometimes to reduce risks, because the component is known to work well, or because the regulation does not allow a more efficient approach to certify the SSCs or the use of more advanced technology, such as additive manufacturing.[473]

The availability of certified suppliers is worsened by the use of different nuclear codes and standards in various countries and regions, which limits the possibility for international sourcing of components and leads to additional certification costs. Furthermore, barriers to exports limit the capacity for sourcing components internationally. [474]

In response to the above supply chain challenges NPP operators in a number of European countries have occasionally used (e.g. BE, CH, FR) or commonly use (e.g. SI) or are in the process of implementing (e.g. CZ, FI, SE) a process called commercial-grade dedication (CGD). The latter is essentially an acceptance process providing reasonable assurance that a component or equipment produced according to non-nuclear industry standards (a commercial item) performs its intended safety function when used for safety-classified SSCs in nuclear facilities. CGD was first introduced in the U.S. after a significant number of U.S. suppliers abandoned their nuclear QA programmes in response to the falling number of new-build projects in the US after the Three Mile Island accident. In European countries with a US based nuclear regulation, like Slovenia and Spain, CGD is accepted by the regulator and common practice. CGD allows NPP operators to procure components and equipment for safety-classified SSCs from suppliers that are not familiar with nuclear requirements and thus increases their pool of potential suppliers. The CGD process is performed by the NPP operator or a competent third-party organisation that acts on behalf of the NPP operator. Thus with CGD the efforts for providing reasonable assurance that the component or equipment in scope performs its intended safety function is essentially shifted from the supplier (who is not familiar with nuclear requirements) to the NPP operator or competent third party organisation.

Evidence of short-term vulnerability to the COVID-19 pandemic

The International Atomic Energy Agency (IAEA) has established a COVID-19 operational experience network. Measures taken by nuclear facility operators include reducing staffing, introducing remote work, hygiene measures, medical screening, self-isolation and travel restrictions.[475] Operators have conducted reviews of spares in order to ensure the availability of critical materials and parts in case of supply chain restrictions. While acknowledging that supply chain restrictions could theoretically have a long-term impact on new nuclear projects or major refurbishments, the IAEA indicates that "no [IAEA] Member State reported the enforced shutdown of any nuclear power reactor resulting from the effects of COVID-19 on their workforce or essential services such as supply chains."[476] It must be noted that business continuity plans of nuclear operators assessed the risks and determined adaptation measures to pandemics already.

A number of NPP planned outages for maintenance or refurbishment have been postponed worldwide. This includes Hungary, where outage activities were reduced due to travel restrictions of staff or foreign suppliers. Restrictions on the number of workers on the site led to a longer outage for refuelling in the Spanish Trillo-1 NPP. The IAEA also indicates that "to help provide a continuous supply of power throughout the winter of 2020-2021, a number of nuclear reactors may have to be taken offline this summer and autumn in order to save fuel on these power plants." [477]

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[472] JRC in World Nuclear Association. (2020). Launch of the World Nuclear Supply Chain: Outlook 2040 report.
[473] Based on: JRC. (2020). Current challenges of the European nuclear supply chain; and FORATOM. (2020) .Optimising the European Nuclear Supply Chain.
[474] International Framework for Nuclear Energy Cooperation. (2017). Global Supply Chain and Localization, Issues and Opportunities: A Conference on the Customer Dialogue – Summary Conference Report. Available at: https://www.ifnec.org/ifnec/upload/docs/application/pdf/2018-12/2017_ifnec_the_summary_report_of_the_conference_global_supply_chain_and_localization_issues.pdf
[475] IAEA. (2020). IAEA Steps up Support for Nuclear Facility Operators during COVID-19 Crisis. Available at: https://www.iaea.org/newscenter/news/iaea-steps-up-support-for-nuclear-facility-operators-during-covid-19-crisis
[476] IAEA. (2020). The operation, safety and security of nuclear and radiation facilities and activities during the COVID-19 Pandemic. Available at: https://www.iaea.org/sites/default/files/20/06/govinf2020-8.pdf
[477] Ibid.

FORATOM provides an overview of the situation of the nuclear sector in its Member Countries.[478] The sector has been recognised as essential in several EU Member States. As seen in the table below, the sector has faced challenges across most of its supply chain stages. Often, measures were taken to ensure the sourcing of personal protective equipment (PPEs). Vattenfall indicates it is in contact with the Swedish government to ensure that operation is not disrupted due to e.g. closure of borders, as some activities need to be done by foreign experts.

Table 5-3 Key challenges faced by the nuclear supply chain since the onset of COVID-19 outbreak

Supply chain stage	Challenge(s) encountered	Short/long-term adaptation measures
Components & sub-components	Difficulties in sourcing components due to manufacturing delays and logistics issues	Remote source verification Identifying high-priority items and suppliers
Transport & distribution	Difficulties in sourcing components due to logistics issues	Examples exist of some spare parts for certain equipment being produced via advanced manufacturing locally, compared to ordering from other countries.
Construction & installation	Social distancing requirements Travel restrictions to foreign suppliers	Introducing remote work, hygiene measures
Operations & maintenance	Difficulties to conduct certain I&M due to specialist resource unavailable, availability of contractors and/or resource for project management of contract, Social distancing requirements Travel restrictions	Reducing staffing, introducing remote work, hygiene measures, medical screening, self-isolation and travel restrictions Classification as essential workers Identifying high-priority items and suppliers
Decommissioning	Difficulties to conduct certain activities with reduced staffing	Greater use of new techniques and enabling technologies such as robotics solutions to support activities.

The European Commission's Energy Security Good Practices to Address Pandemic Risks (detailed in Textbox 5-1) pays particular attention to security of supply in the nuclear sector in face of a pandemic. In the EU, particular attention was made to 'guarantee the continuation of the Euratom safeguard verifications'. Also, 'conducting maintenance in accordance with regulatory approvals, ensuring emergency response capability at all times and, when possible, on-site supply of fuel for more extended periods for some nuclear power plants' was relevant during the pandemic. Any teleworking measures had to be approved by nuclear regulators.[479]

Textbox 5-1 The European Commission's Energy Security Good Practices to Address Pandemic Risks

In June 2020 the European Commission published the document "Energy Security: Good Practices to Address Pandemic Risks". Building on the experience of Member State authorities and economic operators, it identifies short- and long-term risks and challenges as well as 20 good practices for the energy sector are identified to address risks from COVID-19 and other pandemics.

Risks identified by the Commission comprise, in the short-term:

- ensuring energy supply;
- movement and availability of specialised energy workers;
- movement and access for Euratom safeguards inspectors;
- access to components and raw materials that are critical for energy;
- access to protective equipment and medical testing for energy workers;
- business continuity of critical energy infrastructure;
- preparedness to rebound of energy demand;
- cyber and hybrid threat preparedness.

And in the long-term:

- uncertainty regarding the duration of the pandemic;
- specialised workforce unavailability or lower resilience;
- additional unexpected contingencies, including extreme weather events;
- reliability of critical supply chains;

[478] Foratom. (n.d.). COVID-19 Outbreak – FORATOM Statement. Available at: https://www.foratom.org/media/COVID-19/

[479] European Commission. (2020). SWD(2020) 104 final. Energy Security: Good Practices to Address Pandemic Risks. Available at: https://ec.europa.eu/energy/sites/ener/files/1_en_document_travail_service_part1_v3.pdf

- impact of delays of postponing maintenance;
- large project delays and investment reductions;
- non-realistic emergency stockholding for upcoming calendar years;
- loss of control of critical energy assets.

To address these challenges, the good practices proposed are:
- preserving supply to vulnerable customers;
- declaring the energy sector as an essential service;
- preserving free movement for specialised energy workers;
- preserving essential transport flows moving to ensure energy supply chains;
- well-functioning of the internal energy market;
- strong risk preparedness plans;
- strong business continuity and contingency plans;
- solidarity and cross-border coordination, communication and information sharing;
- teleworking for non-shift activities and non-core activities;
- rescheduling non-essential maintenance works;
- hygiene and sanitary measures, as well as training on hygiene protocols;
- cross border assistance, cooperation and training for operators;
- redundancy of control rooms and implementation of remote control;
- establish base camps and reserves of volunteers for critical infrastructure;
- reduction of regular exchange of personal;
- pre-confinement of staff before accessing isolated locations;
- in key locations, early detection, evacuation measures, specific support to workers;
- reinforce cybersecurity measures and cooperation;
- pragmatic risk-based approach by national regulators, in particular the nuclear sector;
- attention to the economic impact on energy companies, subcontractors and investors.

In the US, COVID-19 has led to a number of supply chain challenges, although this has not affected the operation and planned outages of US NPPs. This included shipment delays (including activation of force majeure clauses in contracts) and inability for contractors to travel. Workers were classified as essential as needed, including contractors, to address travel restrictions and stay at home orders. Sourcing personal protective equipment and personal hygiene items was challenging. Verification of supplier shipments (source verification) and auditing of suppliers for (renewal of) certifications was also impacted. [480]

Lessons learned in the US include:[481]
- Identify high-priority items (for operation and outages) and suppliers, communicating and planning sourcing for these
- Designing high-priority suppliers as critical
- Adopting remote source verification approaches
- Alternative methods for sourcing PPE and hygiene items, creating/stocking pandemic ‘kits’

Over a third of participants in an IAEA webinar indicated difficulties in getting supplier of services/technical support on site, and a fifth experienced difficulties in sources safety-related products. A fifth also “proactively ordered products or made other arrangements to avoid any shortage”. ROSATOM indicated it experienced no major disruptions in its construction sites, including the Finnish Hanhikivi-1 NPP, whose construction should start in the coming years. Mid- to long-term measures proposed by ROSATOM include the development of standards for remote interactions and technical support, new remote monitoring technologies, and developing IT systems for the entire supply chain. Remote/hybrid evaluations/audits/inspections and IT solutions were the solutions most supported by webinar participants.[482]

[480] IAEA. (2020). Webinar: COVID-19 and its impacts on the nuclear power supply chain. Available at: https://www.iaea.org/about/organizational-structure/department-of-nuclear-energy/division-of-nuclear-power/nuclear-power-engineering-section/webinar-on-covid-19-and-its-impact-on-the-nuclear-power-supply-chain
[481] Ibid.
[482] Ibid.

5.5. Biomass gasifiers and gas turbines

Introduction and technology description

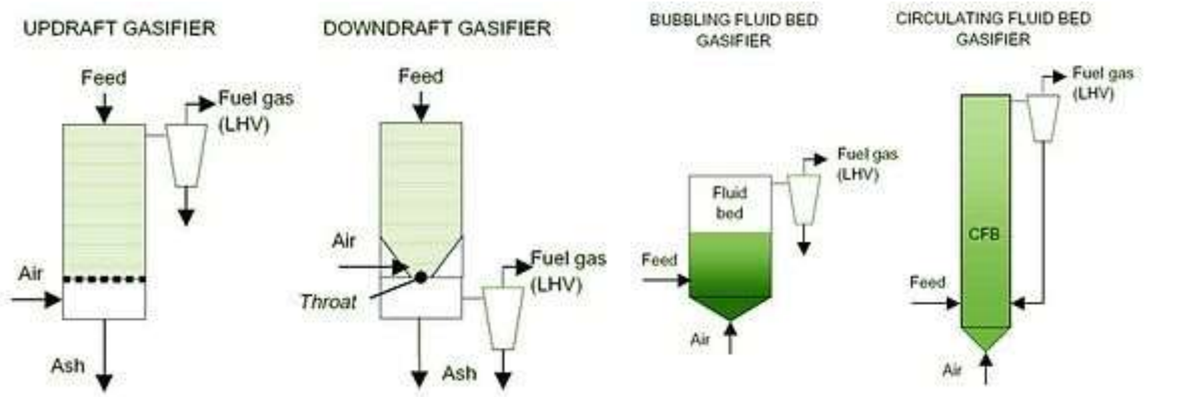
Gas can be used to generate electricity in a variety of ways. Natural gas is most often used as the gas of choice, other relevant sources of gaseous fuels include waste gases (from e.g. waste deposits and industrial processes), hydrogen and synthetic methane. Biogas derived from anaerobic digesters or from the gasification of biomass can also be used in gas turbines to generate electricity.[483]

Biomass Gasifiers[484]

Gasification process converts biomass, a low-energy density material, into a gaseous product, which is a mixture of carbon monoxide, hydrogen, methane and carbon dioxide. The gaseous products from the gasifier can be utilized in gas engines or gas turbines for the generation of electricity (see section below). Gasifiers can be categorized into three main types: fixed bed gasifiers, fluidized gasifiers and the entrained flow gasifiers.

The fixed bed gasifiers are mostly small scale and come in two types, either down-draft (<2 MW) or up-draft (<10 MW). They differ in the direction of gas flow through the biomass in the reactor. In the up-draft gasifiers the raw gas contains important fractions of tar. Therefore, the application of updraft gasification is not suitable for internal combustion engines. The down-draft reactor enables the cracking of the high hydrocarbon fraction but a drawback is the high gas temperature at the outlet. Fluidised bed gasifiers reduce significantly the problems associated with the utilization of agricultural biomass. Entrained flow gasifiers operate at very high temperatures, 1200 to 2000°C and require biomass in form of very finely ground particles. Because of the high temperature, gas is entirely tar free.

Figure 5-24 Schematic of a) fixed bed gasifier and b) fluidised bed gasifier (EBIA, 2021)



A review by the European Biomass Industry Association, of gasifier manufacturers in Europe, USA and Canada identified 50 manufacturers offering "commercial" gasification plants from which:

- 75% of the designs were downdraft type,
- 20% of the designs were fluidized bed systems,
- 2.5% of the designs were updraft type, and,
- 2.5% were of various other designs.

Gas Turbines

Two of the most common gas turbine technologies are:

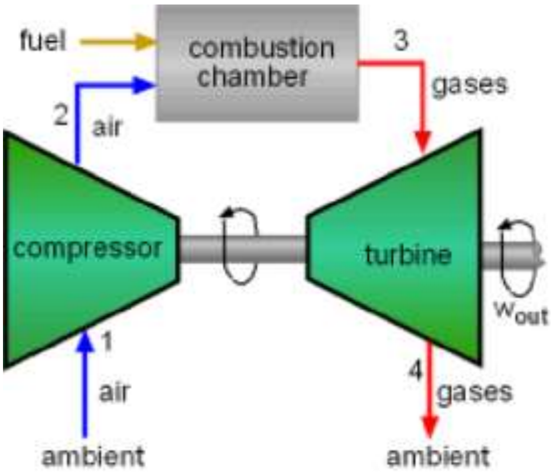
- **Open cycle gas turbine (OCGT) (or Combustion Turbine):** Most gas turbines operate on an open cycle in which air is taken from the atmosphere, compressed in a centrifugal or axial-flow compressor, and then fed into a combustion chamber.
- **Combined cycle gas turbine (CCGT):** CCGT is the dominant gas-based technology for intermediate and base-load power generation. These plants have the same basic components as the OCGT plants, but the heat associated with the gas-turbine exhaust is

[483] It is important to note that presently, gasified biomass constitutes a small share of the overall gas supply for gas turbines. Nonetheless, for the purpose of this study the two technologies are described together based on practical considerations.

[484] Section based on European Biomass Industry Association (2021). Gasification. Available at: https://www.eubia.org/cms/wiki-biomass/pyrolysis-and-gasification/gasification/ and Luo, X. et al. (2018) Biomass Gasification: An Overview of Technological Barriers and Socio-Environmental Impact. Available at: https://www.intechopen.com/books/gasification-for-low-grade-feedstock/biomass-gasification-an-overview-of-technological-barriers-and-socio-environmental-impact

used in a heat recovery steam generator (HRSG) to produce steam that drives a steam turbine and generates additional electric power.[485]

Figure 5-25 Main components of an Open Cycle Gas Turbine Configuration (left) and Combined Cycle Gas Turbine (right)[486]



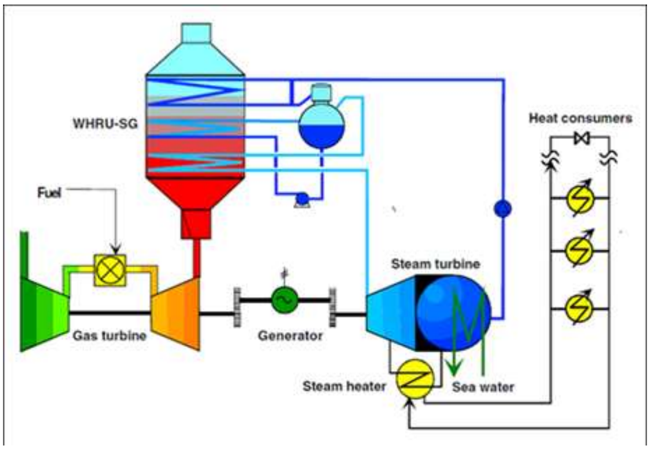


Figure 5-25 presents a simplified representation of the components in OGTC and CCGT technologies. Gas turbines are composed of three main components: compressor, combustor and power turbine. The CCGT is composed additionally of waste heat recovery units for steam generation; steam turbines; condensers; and other auxiliary equipment. Based on the heat recovery principle, the overall electrical efficiency of a CCGT system is typically in the range of 50–60% — a substantial improvement over the efficiency of a OCGT application of around 33%.[487] Given that CCGTs contain the majority of pieces of OCGTs the supply chain analysis will focus on CCGTs.

According to the IEA, the reliance on flexible natural gas-fired power generation is set to increase across the EU driven by the coal-phase-out and some countries' decision to end the use of nuclear energy. Natural gas can support the transition to cleaner fuels, including biomethane and hydrogen.[488] A recent report by the International Energy Agency (IEA), finds that the clearest example of a "quick win" to reduce emissions by fuel switching is by running existing gas-fired plants instead of coal-fired plants for electricity generation. On average, switching from coal to gas cuts emissions by 50% when producing electricity.[489]

Raw and processed materials

Gasifiers are made of metal alloys. They often contain corrosion-resistant materials such as copper, brass, epoxy lined steel and stainless steel.

The components of the gas turbine are made up of several raw and process materials. The composition of these will differ depending on the type and design of the turbine. Initially, the primary focus in choosing the materials was based on high temperature tensile strength requirements. However, as operating temperatures have increased the focus has shifted on stress rupture life (the sudden and complete failure of a material under stress), creep properties (tendency of a material to move slowly or deform under the influence of persistent mechanical, stress) and low cycle fatigue life (characterised by plastic deformation and low cycle phenomenon). Often, production blades for compressors are made from 12% chromium containing martensitic stainless steel (grades 403 or 403 Cb). [490] Combustion hardware has traditionally been made from nickel-base superalloys but has recently shifted to cobalt-base superalloys. Turbine discs of most gas engine single shaft heavy duty

[485] VGP Powertech. (2015). Levelized Cost of Electricity. Available at: https://www.vgb.org/en/lcoe2015.html?dfid=74042
[486] Ipieca. (2014). Open Cycle Gas Turbines. Available at: https://www.ipieca.org/resources/energy-efficiency-solutions/power-and-heat-generation/open-cycle-gas-turbines/
Ipieca. (2013). Combined cycle gas turbines. Available at: https://www.ipieca.org/resources/energy-efficiency-solutions/power-and-heat-generation/combined-cycle-gas-turbines/
[487487] Ibid.
[488] IEA. (2020. European Union 2020. Available at: https://www.iea.org/reports/european-union-2020
[489] IEA. (2019). The Role of Gas in Today's Energy Transitions. Available at: https://webstore.iea.org/the-role-of-gas-in-todays-energy-transitions
[490] Muktinutalapati, N.R.. (2011). Materials for Gas Turbines: An Overview, Chapter in Advances in Gas Turbine Technology. Available at: https://www.intechopen.com/books/advances-in-gas-turbine-technology/materials-for-gas-turbines-an-overview

gas turbines are made of different chromium, iron or nickel alloys. Bucket (rotating airfoils) and nozzel materials for land base gas turbines are also made of different combinations of metal alloys. Given the harsh operating conditions including high firing temperatures and excessive contaminations in the operating environment, the design of superalloy materials is not sufficient, engine blades must be coated with protective material. There are different types of coatings, often divided into aluminium (diffusion), overlay and thermal barrier coatings. There are based either on a combination of metal alloys of from ceramics for the latter type.[491]

Component manufacturing and integration

Major players in gasification are Royal Dutch Shell (NL), General Electric (GE)(US), Air Liquide (FR) and SEDIN Engineering Company Limited (CN), who enjoy dominant positions in the market. Asia-Pacific market is the most dominant with the largest market share at present.[492]

The main components of the gas-turbine are described in the section above (compressor, combustor power turbine, waste heat recovery units). In addition to the turbine, a generator and the balance of plant components are required to run a gas power plant. The table below lists the top ten gas turbine manufacturers in the world in 2018 and the location of their headquarters. Four out of these companies are headquartered in EU27 countries and one of them in the UK. Furthermore, GE Power, Mitsubishi and Solar Turbines all also have a large European footprint including research and production facilities.

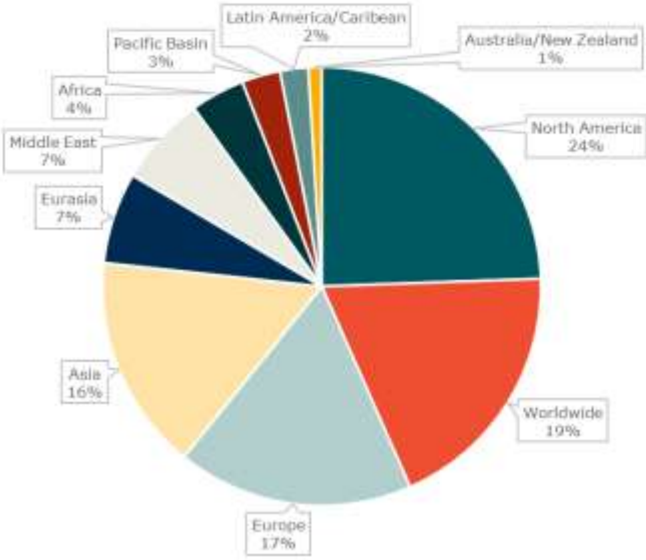
Table 5-4 Top 10 gas turbine manufacturers worldwide in 2018[493]

Name of company	Headquarter
Ansaldo Energia	Genova, Italy
GE Power	Schenectady, NY, US
Kawasaki Heavy Industries	Tokyo, Japan
Mitsubishi Heavy Industries	Tokyo, Japan
Siemens Energy	Berlin and Munich, Germany
Solar Turbines – Caterpillar	San Diego, US
Capstone Turbine Corporation	Van Nuys, California, US
MAN Energy Solutions	Augsburg, Bavaria, Germany
OPRA Turbines	Hengelo, The Netherlands
Centrax Gas Turbines	Newton Abbot, Devon, England

Regarding the geographic distribution of demand for gas turbines, the main markets would be North America (a quarter of the demand in 2018-2027), Europe (over 17%) and Asia (around 16%), as shown in Figure 5-26. North America would see slight growth after the mid-2020s, while European demand for gas turbines would remain constant. In Asia, China is a major market, but the deceleration of the economy and the energy policy priorities create uncertainty for the gas turbine market.[494] Based on the information above, market concentration is not a major concern for the security of supply of gas turbines in the EU27.

[491] Ibid.
[492] MarketandMarket. (2021). Available at: https://www.marketsandmarkets.com/Market-Reports/gasification-market-108290678.html
[493] Technavio. (2018). Available at: https://blog.technavio.com/blog/top-10-gas-turbine-manufacturers
[494] Forecast International. (2018). Worldwide gas turbine forecast.

Figure 5-26 Share of gas turbines additional installed capacity for 2018-2027[495]



Construction, operation and maintenance

Compared to other power plants, natural gas power plans are relatively cheap and quick to build.[496] However, the construction and installation of gas-based turbines requires a technically qualified workforce. Often, the manufacturers of gas-turbines also offer installation and O&M-related services. Companies such as GE, offer customizable O&M service options that involve either advisory services and training or contracting full-service operators to perform all day-to-day operational activities. Contracting options include multi-year agreements, which are based on strategies around performance and can evolve through the plant life cycle. Other services available are outage services, upgrades, field services and plant rehabilitation and relocation services.[497] Furthermore, digitalisation solutions are becoming more and more popular given the opportunities they offer for the transformation of the electricity industry. According to GE, digitalisation solutions can provide early warnings and signal the need for predictive maintenance, enable rapid turn-up and better management of fuel variability and emissions levels using advanced analytics and provide real-time visibility into power production for plant managers and traders among other benefits.[498] However, increased digitalisation of the power sector also poses an increased risk of cyberattacks.

[495] Ibid.
[496] University of Calgary – Energy Education. (2019). Natural gas power plant. Available at: https://energyeducation.ca/encyclopedia/Natural_gas_power_plant
[497] GE Power. (2018). 2018 Power Services Catalog. Available at: https://www.ge.com/content/dam/gepower-new/global/en_US/downloads/gas-new-site/resources/catalog/2018-ps-catalog.pdf
[498] General Electric. (n.d.). Electricity Value Network: Digital Transformations with GE Solutions. Available at: https://www.ge.com/digital/sites/default/files/download_assets/GE-energy-electricity-value-network-infographic.pdf

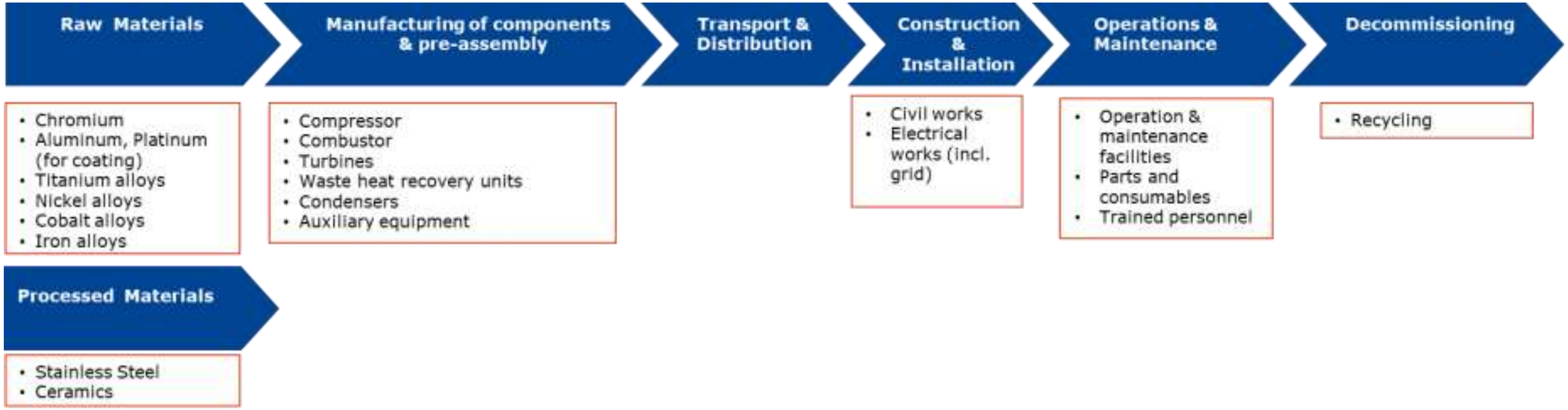
Figure 5-27 Gas Turbines supply chain vulnerability

	Supply chain component	Vulnerable element	Import dependency	Market concentration	Easy of substitutability	Price stability
			Import share - Number of importers/sources	Number of manufacturers/suppliers	Based on evidence from stakeholder interviews	Coefficient of variation
Gas Turbines	Raw and processed materials	Aluminium	59%	43% (RU, DE, MZ, FR)	Medium, by copper	22%
		Chromium	66%	86% (ZA, TR, KZ, IN)	Low	Overall increase from 2012 to 2017
		Cobalt	86%	76% (CD, CN, CA, CU)	Medium	Follow similar trends to those of Ni
		Nickel	59%	59% (CN, RU, JP, CA)	Medium	50%
		Platinum	98%	93% (ZA, RU, ZW)	Still difficult to substitute	The high price of platinum
		Titanium	100%	57% (CA, AU, ZA, CN)	Medium	High volatility
		Steel	21%	44% (Extra-EU) (RU, TR, CN, UK)	Medium	21%
	Components / Equipment / Assembly	Gas turbines	NA	NA	NA	NA
		Gas turbine components	NA	NA	NA	NA

The selection of the highly vulnerable elements is based on the assessment of these criteria, but also on the literature review and stakeholder consultation. Some elements may appear to be highly vulnerable according to the assessment of these criteria, but for several other reasons (e.g. limited amount needed), both the literature and the stakeholders do not lead to the conclusion they should be considered as such. Therefore, these criteria should only be considered as a preliminary assessment of the vulnerability of the elements, which is refined with other information sources.

Figure 5-28 illustrates the gas turbines value chain.

Figure 5-28 Supply chain for gas turbines



Based on the analysis of the supply elements, none of the elements were identified as highly vulnerable. More detailed information is provided below:

Evidence of short-term vulnerability to the COVID-19 pandemic

Regarding supply chain disruption in the gas turbine value chain due to COVID-19, GE states that in the second quarter of 2020, both gas-based electricity generation and GE gas turbine utilization remained stable. During this time the company's orders included six gas turbines, including four aeroderivative units. Furthermore, the company stated that they had observed impacts on their supply chain resulting in delays in parts and equipment output and postponed servicing of customers due to social distancing and travel restrictions. [499] Ansaldo Energia mentioned that heavy duty turbine blades and vanes casting supplies are mostly located outside of Europe and could represent a potential fragility for the European gas turbine supply chain. Furthermore, during the COVID-19 lockdown servicing the gas turbines became a challenge. All gas turbines have defined service intervals during parts are exchanged or upgraded. These routine maintenance services ensure the well-functioning of the gas-fired power plants. While remote monitoring is widely used, in these cases service staff as well as parts need to be on place at the power plant.

[499] Burke J. (2020). COVID-19 'Challenges' GE Power in Second Quarter. Available at: https://www.dieselgasturbine.com/7011679.article

5.6. Hydrogen production, storage and end-use

Introduction and technology description

Hydrogen will be used as fuel for the transportation sector (various modes), for cogeneration of electricity and heat, to produce heat (combustion in boilers) or power (e.g. combustion in gas turbines), as a storage option for electricity and as a feedstock and energy fuel in hard-to-decarbonise industry, as well as for direct use of hydrogen in small scale stationary end-uses.
Considering the European Hydrogen Strategy, the electrolysers are now seen even more 'strategic' that fuel cell.

The Hydrogen Production, Storage and Use supply chain comprises

- Hydrogen fuel cells (stationary & mobile applications);
- Other end-use applications (industrial processes e.g. H2 replacing coking coal in iron industry; gas turbines; conventional boilers; …);
- Renewable hydrogen production (the recently launched "Hydrogen Strategy for a climate neutral Europe"[500] aims at fostering a significant growth in European electrolyser capacity)
- Hydrogen storage (stationary and mobile applications)

Hydrogen fuel cells (HFCs) are electrochemical devices converting hydrogen gas and oxygen directly into electrical energy without combustion, producing water. The fuel cell consists of two electrodes—a negative electrode (or anode) and a positive electrode (or cathode)—sandwiched around an electrolyte. Hydrogen, as fuel, is fed to the anode, and air (oxygen) is fed to the cathode. A catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat.

Several FC types are available today, capable of operating under different conditions depending on the type of fuel, operation temperature and the type of electrolyte: Polymer Electrolyte Membrane FC (PEMFC) ; Phosphoric Acid F (PAFC) ; Alkaline FC (AFC) ; Molten Carbonate FC (MCFC) ; Solid Oxide FC (SOFC) ; Direct-Methanol FC (DMFC). PEMFC technology is currently the most popular, having the higher power density and operating at relatively low temperatures compared to other FC types, which makes it ideal for the automotive sector (e.g. FC light duty vehicles, FC buses, heavy duty vehicles, trains, airplanes, ships)[501], forklifts, data centres and backup power systems. SOFC are also employed for combined heat and power production, due to its higher efficiency, but its high operational temperature is disadvantageous for transport applications.

Most FCs have a standard design in which two electrodes are separated by an ion-conducting electrolyte. The heart of a PEM FC is the membrane electrode assembly (MEA), which includes five basic components: membrane, anode catalyst layer, cathode catalyst layer and two gas diffusion layers (GDLs) one for each electrode. Individual cells are assembled in a fuel cell stack to achieve a higher voltage and power. A stack is finished with end plates and connections for ease of integration with the balance of plant components.

FCs use catalysts, commonly made from platinum-group metals (PGMs), given their unique chemical and physical properties. PGMs-based catalysts bear primary responsibility for converting hydrogen energy into electrical power. The fuel cell power plant size, cost, and durability are all directly linked to the catalyst. Due to high platinum material costs, PEMFC cost is sensitive to the amount of catalyst required.[502] Hence, researchers are continuously trying to reduce or eliminate these metals in FCs (a FC vehicle needs 10 times more than the PGM loading of an average gasoline or diesel vehicle[503]), to decrease costs, raw material dependency, and durability. Figure 5-29[504] illustrates some of the raw materials used in FCs.

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[500] European Commission. (2020). A Hydrogen Strategy for a climate neutral Europe. Available at: https://ec.europa.eu/commission/presscorner/api/files/attachment/865942/EU_Hydrogen_Strategy.pdf.pdf

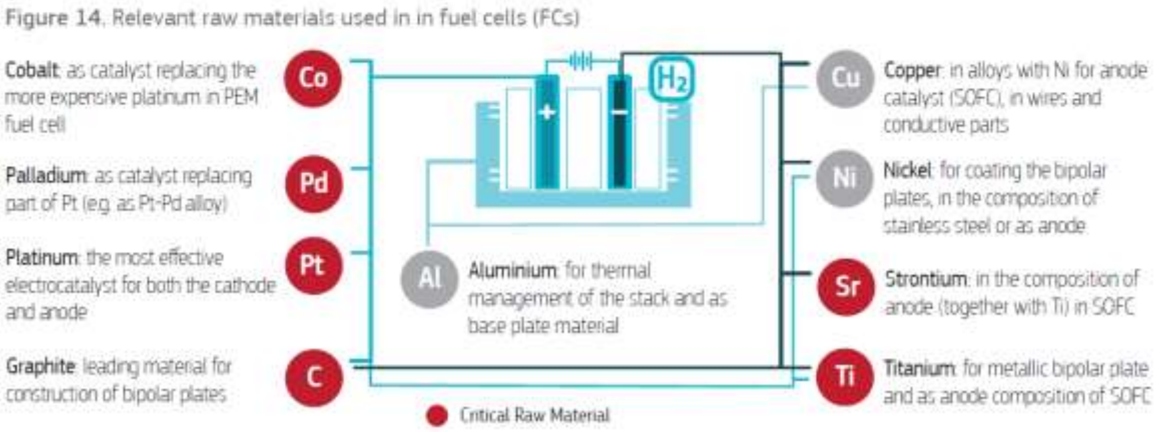
[501] Blagoeva, D., Pavel, C., Wittmer, D., Huisman, J. and Pasimeni, F. (2019). Materials dependencies for dual-use technologies relevant to Europe`s defence sector, EUR 29850 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-11101-6, doi:10.2760/279819, JRC117729.

[502] James, B.D., Huya-Kouadio, J.M., Houchins, C., DeSantis, D.A. (2017). Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2016 Update. Available at: https://energy.gov/sites/prod/files/2017/06/f34/fcto_sa_2016_pemfc_transportation_cost_analysis.pdf

[503] Hao, H., Mu, Z., Liu, Z., & Zhao, F. (2018). Abating transport GHG emissions by hydrogen fuel cell vehicles: chances for the developing world. Frontiers in Energy, 12(3), 466-480.

[504] JRC. (2020). Study on the EU's list of Critical Raw Materials. (JRC, 2020). Available at: https://ec.europa.eu/jrc/en/news/jrc-assesses-critical-raw-materials-europe-s-green-and-digital-future

Figure 5-29 Relevant raw materials & components in fuel cells



Source: Study on the EU's list of Critical Raw Materials

Regarding their operation, fuel cells require limited maintenance and zero lubricants.

Regarding hydrogen production, several types of electrolysers are available today, operating under different conditions and having different characteristics: Alkaline Electrolysis (AEL); Polymer Exchange Membrane (PEMEL); Solid Oxide Electrolysis – high temperature (SOEL); Anion Exchange Membrane (AEMEL).

According to the study on Value Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cells Technologies[505], no particular material or component stands out in cost or supply risk. The main cost contributors are the cell components – anode and cathode, as well as the bipolar plates and the membrane or diaphragm, depending on the specific design. Some system integrators use their own proprietary membrane chemistries, while others source from a limited selection of suppliers globally.

As outlined in the Hydrogen Strategy, upscaling hydrogen generation will entail developing to larger size, more efficient and cost-effective electrolysers, together with mass manufacturing capabilities and new materials. Research can play a key role in increasing electrolyser’s performance and reducing its costs, by increasing the durability of membranes for PEM, while reducing their critical raw materials content.

Solutions for hydrogen production at lower technology readiness[506] is also essential for the global hydrogen economy and expected uptake but is not addressed in this assessment.

In order to complete the new hydrogen technological chain, infrastructure is needed to transport (even long distance), distribute, store and deliver hydrogen.

The supply chain of hydrogen production, storage and use

According to the EU's list of Critical Raw Materials[507] and the Materials dependency for dual-use technologies relevant to Europe's Defence sector study (JRC 2020[508]), around 30 raw materials are needed for producing FCs and hydrogen mobile storage technologies. Of these materials, 14 materials are deemed critical for the EU economy according to the 2020 CRM list (namely cobalt, magnesium, REEs, platinum, palladium, borates, silicon metal, rhodium, ruthenium, graphite,

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[505] E4tech (UK) Ltd for FCH 2 JU in partnership with Ecorys and Strategic Analysis Inc. (2019). Study on Value Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cells Technologies (FCH contract 192) – Evidence Report. Available at: https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf

[506] For example, direct solar water splitting, or high-temperature pyrolysis processes, (cracking of methane into hydrogen, with solid carbon-black as side product). In the case of biomass-based production (bio generation from bio-methane, bio-gas, vegetable oils) and from marine algae (biochemical conversion), a particular attention is to be paid to sustainability requirements.

[507] Ibid.

[508] Blagoeva, D., Pavel C., Wittmer, D., Huisman, J. and Pasimeni, F. (2019). Materials dependencies for dual-use technologies relevant to Europe's defence sector, EUR 29850 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-79-11102-3, doi:10.2760/570491, JRC117729

lithium, titanium, iridium[509] and vanadium).[510] Raw materials, processed materials, components and their assembly along the supply chain are presented in Figure 5-31.

The components for **alkaline electrolysers** can generally be sourced within Europe.[511] Most of the components used in anode, cathode and bipolar plates are more-or-less standard industrial materials, produced to the specifications of the system integrators. The diaphragm materials are crucial for performance and although standard materials exist, some system integrators use their own proprietary designs.

The **PEM electrolysis** supply chain shares some similarities with its alkaline counterpart as far as system components are concerned[512], though since there is no liquid electrolyte to be pumped and filtered, the PEM balance of plant is simpler. Regarding the stack components, PEM electrolysers are similar to PEM fuel cells to some extent, though due to the higher voltages in electrolysers, corrosion-resistant materials such as titanium are used. Regarding catalyst compositions, PEM electrolyser are different from PEM fuel cells. To conclude, for PEM electrolyser, the main cost contributors to the system are the stack (40%-60%), followed by the power electronics, with Titanium-based bipolar plates and meshes.
PEM hydrogen electrolysers manufacturing relies on the same 14 raw material as fuel cells and hydrogen mobile storage technologies, with an increased use of Titanium.

The supply chain of **solid oxide electrolysers** (SOEL, still at demonstration stage) resembles to solid oxide fuel cells for most of its components, plus some hydrogen-conditioning balance of plant as in all other electrolyser technologies.

The supply chain for compressed tanks is made of high-grade carbon fibres, pressure vessel, a balance of plant (including in-tank pressure regulators, where used), and composite materials.[513]

The hydrogen production, storage and end-use value chain can be separated into the stages shown in Figure 5-31. Previous research has identified several critical elements, predominantly, in the raw materials and compounds block of the supply chain.

The selection of the highly vulnerable elements is based on the assessment of the following criteria (Figure 5-30), but also on the literature review and stakeholder consultation.

[509] Iridium is an ideal catalyst for the electrolytic production of hydrogen from water, but it is extremely expensive. However, a new kind of electrode made of highly porous material does an excellent job with just a hint of iridium.
[510] According to several stakeholders (Hydrogen Europe Research), other raw materials are used such as Chromium (for inox for Bipolar Plates), Gold (for Bipolar Plates coating), Iron (for hoses and structures), Lanthanum (for SOC), Nickel (inox), and Yttrium (for SOC). According to the same stakeholders (HER), in the list of the retained raw materials, some are of minor use (or not used at all), such as Borates, Lithium, Magnesium, graphite and Silicon metal.
[511] E4tech (UK) Ltd for FCH 2 JU in partnership with Ecorys and Strategic Analysis Inc. (2019). Study on Value Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cells Technologies (FCH contract 192) – Evidence Report. Available at:
https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf
[512] Ibid.
[513] James. B.D., Moton, J. M., and Colella, W. G. (2013). Hydrogen Storage Cost Analysis. Available at:
https://www.hydrogen.energy.gov/pdfs/review13/st100_james_2013_o.pdf

Figure 5-30 Vulnerabilities in the HFC & hydrogen storage supply chain

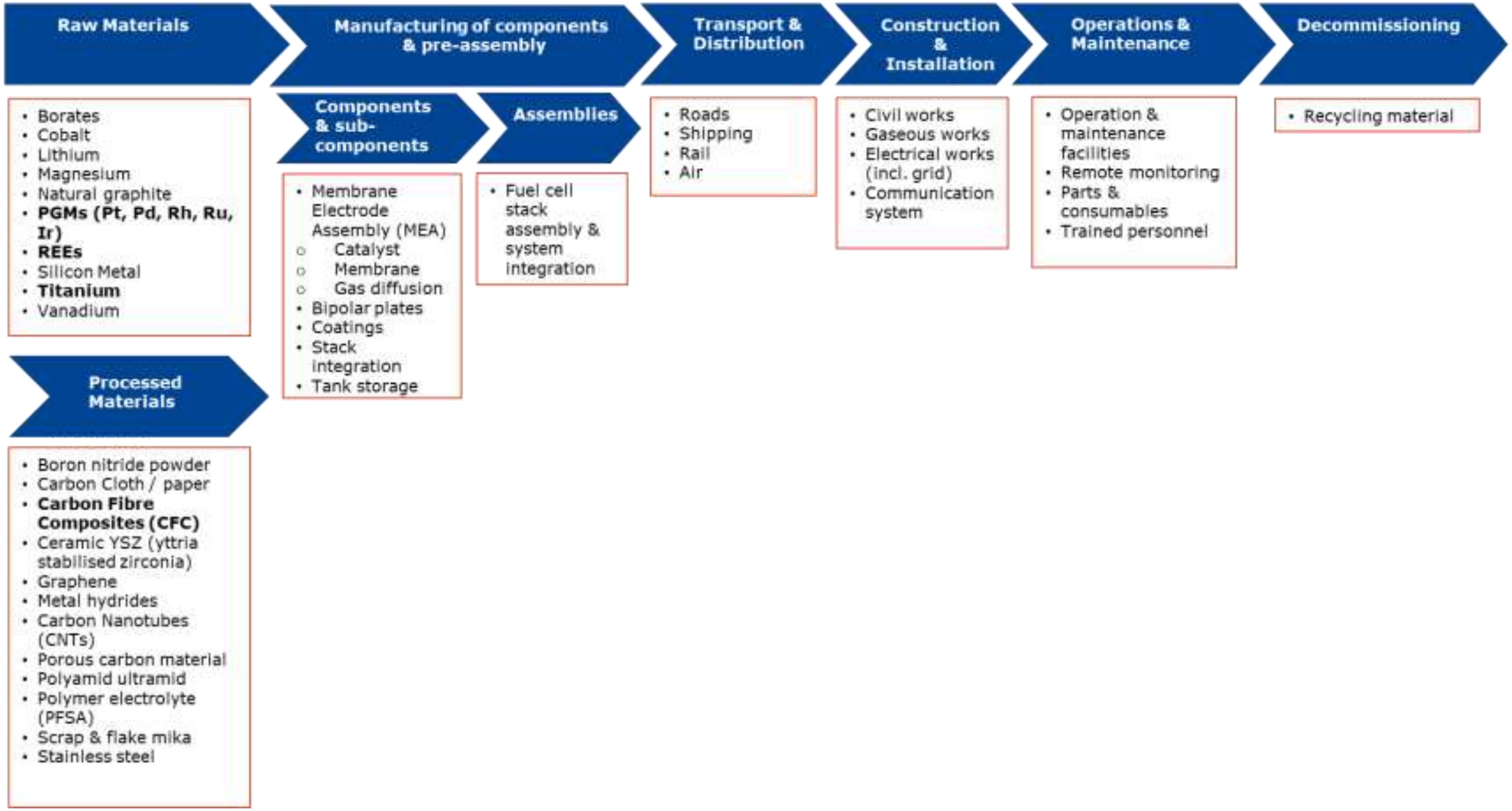
	Sypply chain stage	Vulnerable element	Import dependency	Market concentration	Easy of substitutability	Price stability
			Import reliance	CR4 / Main suppliers	Qualitative analysis	Coefficient of variation
HFC & hydrogen storage	Raw materials	Boron	100%	99% (TR, AR, NO, BO)	Low	Downward trend since mid-2000s
		Cobalt	86%	CD-64% CN-5% CA-5% AU-4% ZM-4% RoW-18%	substitute for PGMs	50%
		Lithium	100%	CL-44% AU-32% AR-11% CN-5% RoW-8%	NA	Downword trend since mid-2018
		Magnesium	100%	CN-87% US-5% IL-3% RoW-5%	NA	~10% (4 years)
		C (natural graphite)	98%	CN-69% IN-12% BR-8% RoW-11%	Synthetic graphite	NA
		PGM: Platinum, Palladium, Ruthenium, Rhodium, Iridium	98%	Platinum ZA-71% RU-16% ZW-6% RoW-7%	Still difficult to substitute	The high price of platinum
		REE	100%	CN-95% US-2% RoW-3%	NA	NA
		Silicon Metal	EU import ~93%	CN-61% BR-10% Europe-7% US-6% RoW-16%	NA	NA
		Titanium	100%	CA-21% AU-15% ZA-12% CN-9% RoW-43%	NA	The high price of Titanium (important for electrolysers)
		Vanadium	98-100%	CN-53% ZA-25% RU-20% RoW-2%	NA	NA
	Processed materials	Carbon Fibre (for pressure vessel)	high IR	NA (from CN, USA)		NA
	Components / Equipment / Assembly	FC assembly	EU import ~99% (but EU production increasing)	NA	NA	NA

Notes: CR4 – concentration ratio of 4 largest suppliers. Extra-EU – CR only for third country suppliers.
Sources: Eurostat PRODCOM/COMEXT; JRC. (2020). Study on the EU's list of Critical Raw Materials; other sources listed in section.

Some elements may appear to be highly vulnerable according to the assessment of these criteria, but for several other reasons (e.g. limited amount needed), both the literature and the stakeholders do not lead to the conclusion they should be considered as such. Therefore, these criteria should only be considered as a preliminary assessment of the vulnerability of the elements, which is refined with other information sources.

Vulnerable elements are highlighted in bold in the following Figure 5-31 illustrating the hydrogen production, storage and end-use value chain.

Figure 5-31 The supply of hydrogen fuel cells & hydrogen storage technologies



*Note: vulnerable elements found highlighted in **bold**.*

The vulnerability assessment shows no supply issues for the processed materials or the components, except for carbon fibre to a certain point. The assessment does show a vulnerability for the supply of raw materials (PGMs, REEs and Titanium). However, the assembly of fuel cell stacks and systems was critical still a few years, meanwhile this is evolving to be less and less the case. Most fuel cell assemblers and system integrators are headquartered outside EU, but the activity has evolved rapidly these last years and assemblers are raising production capacities and assembling activities in Europe. However, despite the increasing number of EU players, as there is currently no evidence that stack design and cell assembly is no longer a weakness for the EU, this should be monitored closely.

The main vulnerabilities, highlighted in bold in Figure 5-31, are developed below:

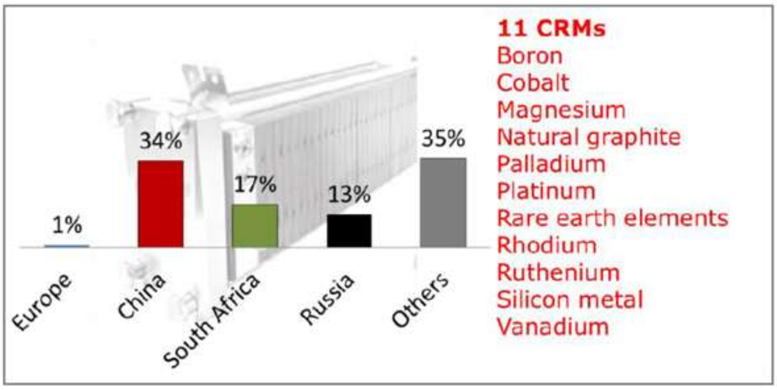
Raw and processed materials

Platinum is produced mainly in South Africa (71% of global production), followed by Russia (16%) and Zimbabwe (6%). The other PGMs, namely palladium, rhodium and ruthenium are also supplied predominantly by three key suppliers: Russia, South Africa and Zimbabwe.

According to the Fuel Cell and Hydrogen Annual Review (2017[514]), based on PGM Market Report from Johnson Matthey[515] data, fuel cells remain currently a tiny fraction of total PGM (in particular Platinum) demand (~150 000 ounces vs more than 6 million ounces).

The global supply of all raw materials required in FC technology is diversified with more than half of the materials coming from a variety of suppliers, each with a small supply share of less than 7%. China, with more than 20% share, is the major supplier of raw materials, followed by South Africa and Russia. Regarding CRMs used in fuel cells, China has the dominant position with 34%, as illustrated by Figure 5-32, followed by South Africa and Russia. Among these raw materials, only PGMs, REEs and titanium are considered highly vulnerable.

Figure 5-32 Supply of CRMs for fuel cells ad hydrogen technologies: key players



Source: European Commission, 2017, Study on the review of the list of critical raw materials

Scientists are currently developing and studying fuel cell catalysts that don't use platinum, but speed up important fuel cell reactions.[516] The most promising platinum-free catalyst for use in the ORR can be based on iron, nitrogen and carbon.

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[514] 4th Energy Wave. The Fuel Cell and Hydrogen Annual Review. (2017). Available at: https://static1.squarespace.com/static/59f093254c0dbf084e7c521b/t/5a34089971c10b467be38de0/1513359529546/FuelCellandHydrogenAnnualReview2017.pdf

[515] Johnson Matthey. (2017). PGM Market Report – May 2017. Available at: http://www.platinum.matthey.com/services/market-research/may_2017_pgm_market_report

[516] PHYS.ORG. (2020). Platinum-free catalysts could make cheaper hydrogen fuel cells. Available at: https://phys.org/news/2020-05-platinum-free-catalysts-cheaper-hydrogen-fuel.html

In addition to raw materials, 12 processed materials (namely Porous carbon material; Polymer electrolyte – Perfluorinated Sulfonic Acid (PFSA[517]); yttria stabilised zirconia ceramic; Carbon Fibre Composites (CFC); Graphene; Carbon Cloth / paper; Stainless steel; Carbon Nanotubes (CNTs); Scrap & flake mika; Metal hydrides; Polyamid ultramid; Boron nitride powder) are identified as the most relevant processed materials for FC and hydrogen storage/production technologies.[518] Europe appears to be the major supplier of processed materials for fuel cells (40 %), followed by the USA (28 %), China (10 %) and Japan (7 %).[519] Other countries provide only around 15 % of the processed materials. The countries' production shares of FC and Hydrogen technologies relevant processed materials are displayed in Figure 5-33.

Europe also enjoys relatively strong position in terms of supplying components, providing around 25 % of global supply, behind North America (44 %), followed by Asia (31 %). Europe has the capacity to produce all major components used in FC, namely Bipolar Plates, catalysts, Gas Diffusion Layers, membranes and hydrogen vessels.

There are plenty of suppliers for metallic tanks which are therefore not deemed critical. Composites tanks (especially composite tanks such as carbon fibre with a polymer liner - thermoplastic) are an emerging technology and there are only a few suppliers.[520]

Europe has strong skillsets in a wide range of **storage technologies** at many scales, including world-leading science in novel storage technologies. For the different technologies mentioned above, Europe is generally well-positioned, with suppliers or developers in all areas. Although compressed storage appears to have many players, not all produce tanks in Europe (hydrogen compressed tank supply has some strong Asian and North American players, with specialist materials coming more from Asia[521]), which remains a weakness in the supply chain. However, Europe has a base of high-quality balance of plant component suppliers such as OMB Saleri in Italy and Pressure Tech in the UK, which would be well positioned to supply a growing market.

As illustrated by Figure 5-33, carbon fibres (key material for compressed storage) production seems to be diversified, with the higher concentration in the USA and Asia countries, but already with a small basis in Europe.

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517 According to some stakeholders, PFAS supply could become an issue for Europe.

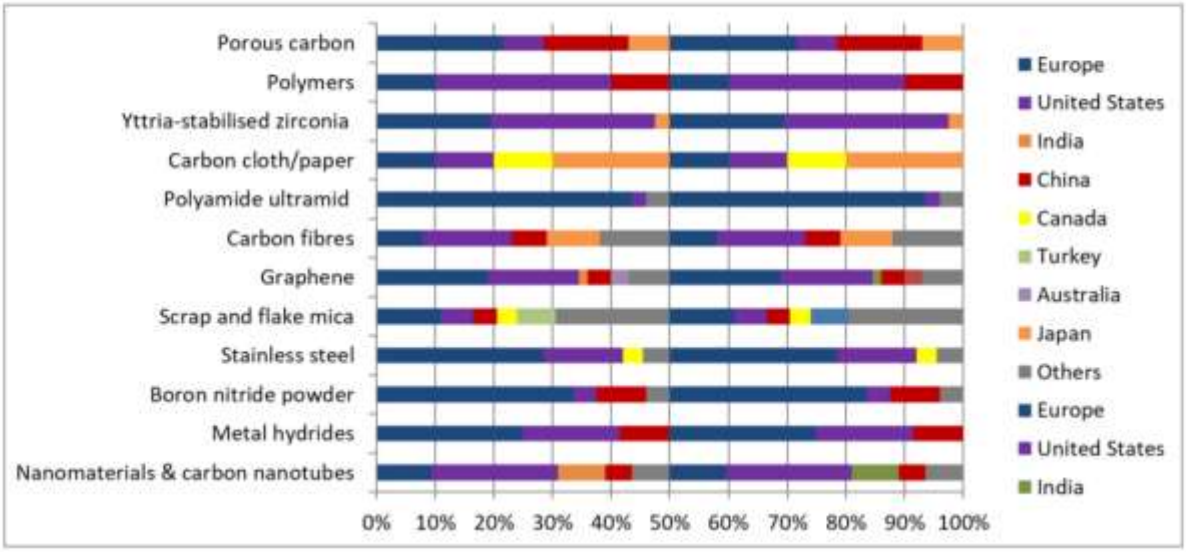
518 According to several stakeholders (Hydrogen Europe Research), other processed materials such as composite polymers (for Bipolar Plates and tanks), fibre glass (for tanks), metal alloys (nickel-chromium-iron), stainless steel. According to the same stakeholders (HER), in the list of the retained raw materials, some are of minor use (or not used at all), such as graphene, scrap and flake mica.

519 Blagoeva, D., Pavel, C., Wittmer, D., Huisman, J. and Pasimeni, F. (2019). Materials dependencies for dual-use technologies relevant to Europe`s defence sector, EUR 29850 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-11101-6, doi:10.2760/279819, JRC117729.

520 According to the Materials dependency for dual-use technologies relevant to Europe’s Defence sector (JRC, 2020), are based in Europe (Hexagon Raufoss, Hexagon X-perion, Raigi, Ulit SA, Optimum CPV, Faber Cylinders, Tenaris), in USA (Luxfer, Volute), in Japan (Toyota)

521 E4tech (UK) Ltd for FCH 2 JU in partnership with Ecorys and Strategic Analysis Inc. (2019). Study on Value Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cells Technologies (FCH contract 192) – Evidence Report. Available at:
https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf

Figure 5-33 Country production shares of processed materials relevant to fuel cell and hydrogen technologies[522]

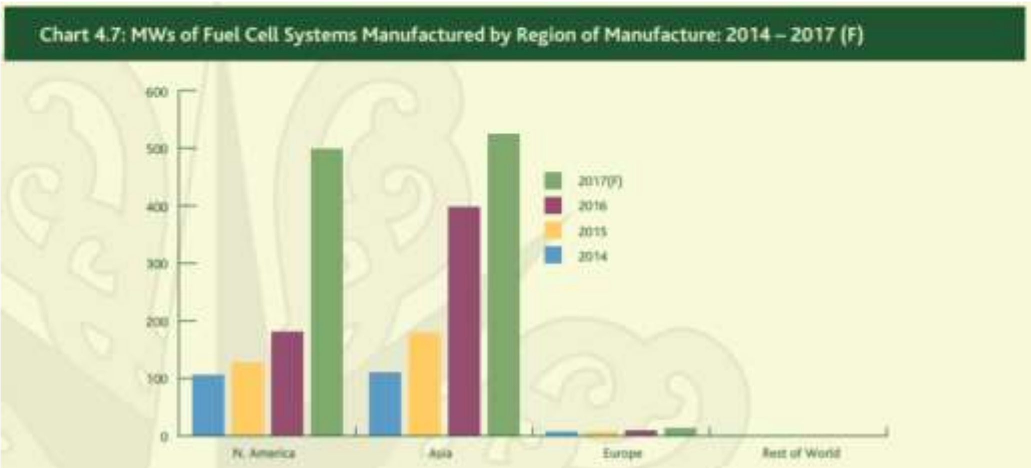


Current tanks are very similar between suppliers - a cheaper, lighter or otherwise better-performing tank developed elsewhere could change markets rapidly.

Components manufacturing and integration

Finally, the stack design and cell assembly are very important steps that can influence the performance of fuel cells and distribution of reactants in the cell stack. The cell assembly will also affect the contact behaviour of the bipolar plates with the membrane electrode assembly (MEA).
The market share 2014-2017 of the Fuel Cell System Manufacturing is shown by region in Figure 5-34. However, this market share is evolving, as more and more hydrogen players are developing their assembly activity across Europe.

Figure 5-34 MWs of Fuel Cells Systems manufactured by region of Manufacture between 2014 and 2017[523]



Around 280 companies are active in the production and supply chain of electrolysers in Europe, although the total European production capacity for electrolysers is currently below 1 GW per year.
The electrolysis market is very dynamic. Globally, the key players of the global water electrolysis market are ThyssenKrupp AG, Linde AG, Air Products and Chemicals Inc., ITM Power, NEL Hydrogen,

[522] Blagoeva, D., Pavel C., Wittmer, D., Huisman, J. and Pasimeni, F. (2019). Materials dependencies for dual-use technologies relevant to Europe's defence sector, EUR 29850 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-11102-3, doi:10.2760/570491, JRC117729.
[523] According to 4th Energy Wave. (2017). Fuel Cell and Hydrogen Annual Review, 2017. Available at: https://static1.squarespace.com/static/59f093254c0dbf084e7c521b/t/5a34089971c10b467be38de0/1513359529546/FuelCellandHydrogenAnnualReview2017.pdf

Siemens AG, McPhy ProtonOnsite, Teledyne Energy Systems Inc., AREVA H2Gen, Siemens, Hydrogenics Corporation, Erre Due SpA, and Peak Scientific.[524,525]

Europe is one of the leaders in today's global **alkaline electrolysis** industry[526] with the two major manufacturers[527] producing in Norway and Belgium respectively, and with other companies[528] gaining momentum. Major players[529] have technologies used for chlor-alkali production which could be used for water electrolysis. China, Japan and the US also have production capacity, but are less active in the global market than the European actors. European companies are positioned well to benefit from market growth. Market analysis shows that electrolysers based on alkaline electrolysis (AEL), are provided by nine EU producers (four in Germany, two in France, two in Italy and one in Denmark), two in Switzerland and one in Norway, two in US, three in China, and three in other countries (Canada, Russia and Japan).

Electrolysers based on **proton exchange membrane (PEM) electrolysis** (much younger technology than alkaline), are provided by six EU suppliers (four in Germany, one in France and one in Denmark), one supplier from UK and one from Norway, two suppliers from US, and two suppliers from other countries. Several North American companies have developments or products[530] (historically, its commercialisation was pioneered in the US, building on developments for the military), now in partnership with EU companies[531]. European developers[532] are also commercialising their own PEM electrolysers, most of them in view of expected market growth as part of the energy transition. Europe is globally well positioned all along the PEM electrolyser supply chain, however, the electrolyser specific supply chain is in general less developed compared with PEM fuel cells as there are fewer electrolyser manufacturers.

An initiative of five countries (Germany, the Netherlands, Denmark, Sweden and Norway) to restrict and ultimately ban the manufacture and use of all PFAs ("per and polyfluorinated alkyl substances"), including fluoropolymers, in Europe has been launched mid of 2020. This initiative is called **the EU PFAS Strategy**[533]. The unintended impact of an insufficiently considered ban on all PFAs would be to severely inhibit the manufacture and use of PEM fuel cells and electrolysers, because at their heart they depend on gas impermeable proton conducting fluoropolymer membranes (PFSA). While there are currently no alternatives. This may increase the vulnerability for the supply of polymer electrolytes.

Electrolysers based on **solid oxide electrolysis**, are manufactured by three suppliers from EU (two in DE and FR) and one from the US.[534]

According to the report on progress of clean energy competitiveness (COM(2020) 953[535]), Asia (mostly China, Japan and South Korea) dominates the total number of patents in the period from 2000 to 2016 for the hydrogen, electrolyser and fuel cell groupings. Nevertheless, the EU performs very well and has filed the most "high value" patent families in the fields of hydrogen and electrolysers. Japan, instead, filed the largest number of "high value" patent families on fuel cells.

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[524] Market Research Future. (2020). Global Water Electrolysis Market. Available at: https://www.marketresearchfuture.com/reports/water-electrolysis-market-4133

[525] According to 4th Energy Wave. (2017). Fuel Cell and Hydrogen Annual Review, 2017. Available at: https://static1.squarespace.com/static/59f093254c0dbf084e7c521b/t/5a34089971c10b467be38de0/1513359529546/FuelCellandHydrogenAnnualReview2017.pdf

[526] E4tech (UK) Ltd for FCH 2 JU in partnership with Ecorys and Strategic Analysis Inc. (2019). Study on Value Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cells Technologies (FCH contract 192) – Evidence Report. Available at: https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf

[527] Nel and Hydrogenics

[528] such as McPhy

[529] such as ThyssenKrupp

[530] including Giner

[531] Such as Spanish company H2B2, and Proton OnSite, now owned by Norway's Nel, as well as Hydrogenics in Canada

[532] such as Siemens, Areva, and ITM Power

[533] European Commission. (2020). Poly- and perfluoroalkyl substances (PFAS). Available at: https://ec.europa.eu/environment/pdf/chemicals/2020/10/SWD_PFAS.pdf

[534] E4tech (UK) Ltd for FCH 2 JU in partnership with Ecorys and Strategic Analysis Inc. (2019). Study on Value Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cells Technologies (FCH contract 192) – Evidence Report. Available at: https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf

[535] European Commission. (2020). COM(2020) 953 final. Progress of clean energy competitiveness. Available at: https://ec.europa.eu/energy/sites/ener/files/report_on_clean_energy_competitiveness_com_2020_953.pdf

Evidence of short-term vulnerability to the COVID-19 pandemic

The economic crisis following the COVID-19 pandemic may cause a significant delay in the adoption and commercial uptake of clean hydrogen production and applications. The problems the hydrogen players may face are more linked to the slow down in the downstream industry than to disruptions in the supply of (raw & processed) materials and compounds. More globally, climate and green investments are being stopped or at least delayed due to economic and policy factors.

Considering the upstream part of the chain, Hydrogen Europe[536] does not indicate specific vulnerabilities of the European hydrogen technologies supply chain to the COVID-19 pandemic. According to the PGMs Market Report (May 2020), PGMs supply and demand will be severely impacted by the COVID-19 pandemic[537], mainly due to troubles in the downstream industry (autocatalyst demand will contract; industrial consumption will fall overall, but with significant variation between applications and regions). Meanwhile, these troubles may possibly have an indirect impact on the global supply of PGMs, and consequently on the fuel cell industry.

According to the Post COVD-19 and the Hydrogen Sector Analysis (Hydrogen Europe, 2020[538]), this economic crisis may even endanger the clean hydrogen sector on the long-term. As a result, the clean hydrogen sector faces three major risks:

- in the short term, small, innovative companies which form the backbone of the technology providers are likely to suffer a **major shortage of liquidity** due to a steep drop in revenues which will result in staff cuts or even bankruptcy;
- large companies which were planning **major investments** in clean technology are likely to **abandon or severely scale-down** these plans, believing that climate and environmental policy commitments will take a backseat in economic recovery plans in Europe and elsewhere;
- **investors** may, for the reasons as presented above, be **less inclined** to finance the planned growth of the sector. Large companies have scaled down or abandoned planned investments in the sector, due to a feared de-prioritisation of climate and energy policies;

Investors are also already fleeing from any risky assets to the safety of cash, gold and other safe assets which is driving the share market down. Consequently, long term investors, including pension funds, facing big reduction of their asset valuations will be reluctant to invest in risky projects and risky SMEs.
Almost all investment activity has faced some disruption due to lockdowns, whether because of restrictions on the movement of people or goods, or because the supply of machinery or equipment was interrupted. But, according to IEA[539], the larger effects on investment spending in 2020, especially in oil, stem from declines in revenues due to lower energy demand and prices, as well as more uncertain expectations for these factors in the years ahead. It is yet unclear whether these low prices will continue, which could therefore seriously compromise the competitiveness of clean technologies. This scenario would increase government's role and support to continue incentivizing the energy transition and related green investments.

Furthermore, although the hydrogen sector is still in its early stage of development, it is mature enough and ready for a fast uptake. Possible troubles and disruptions in the supply of raw and processed materials, and in all fuel cells and hydrogen storage compounds would potentially increase hydrogen's supply chain vulnerability.

[536] Hydrogen Europe. (2020). Post COVID-19 and the hydrogen sector. Available at: https://hydrogen.spade.be/wp-content/uploads/2021/04/Post-COVID-19-for-the-Hydrogen-Sector_fin.pdf
[537] Johnson Matthey. (2020). PGM Market Report: May 2020. Available at: https://matthey.com/en/news/2020/pgm-market-report-may-2020
[538] Hydrogen Europe. (2020). Post COVID-19 and the hydrogen sector. Available at: https://hydrogen.spade.be/wp-content/uploads/2021/04/Post-COVID-19-for-the-Hydrogen-Sector_fin.pdf
[539] IEA. (n.d.). COVID-19. Available at: https://www.iea.org/topics/COVID-19

5.7. Gas infrastructure

Introduction and technology description

Gas infrastructure can be schematised as links and nodes. Transmission and distribution lines operating at a certain pressure are the links, which serve to connect the nodes, which can be liquefied natural gas (LNG) terminals (for liquefaction or regasification), underground storage sites, interconnection points between different pipelines, or connection points to distribution networks (so-called city gates).

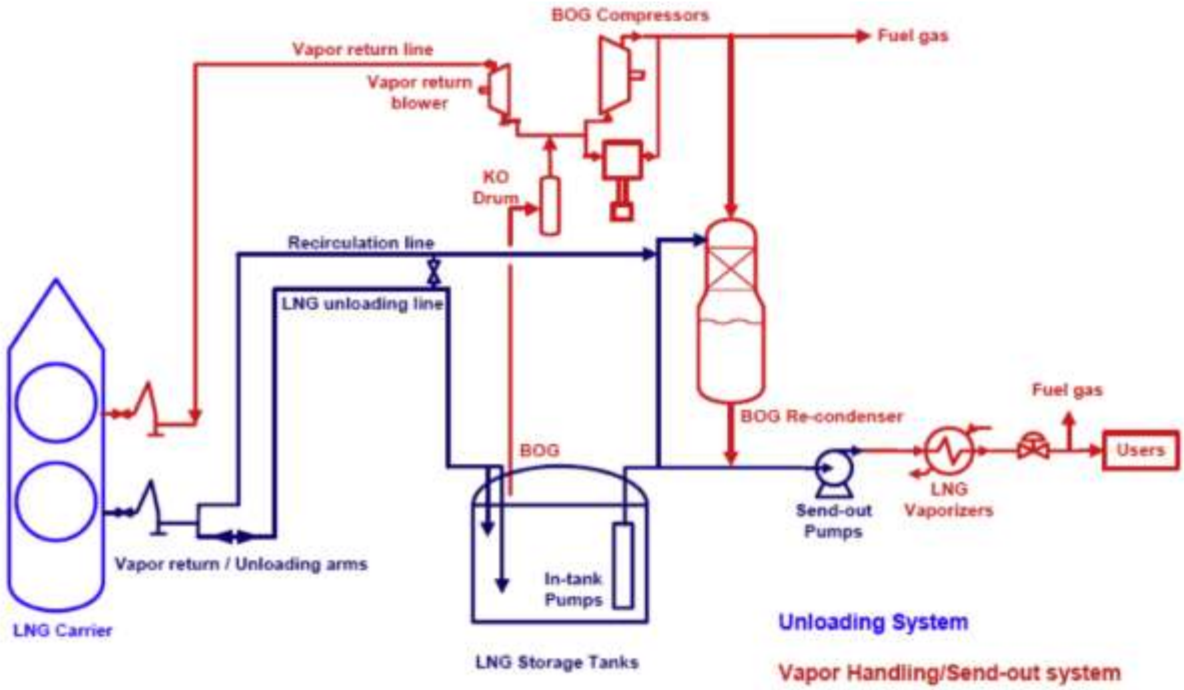
Gas networks can be divided between transmission and distribution, or between pressure levels (typically high, medium and low pressure). The diameter of transmission pipelines typically ranges from 20 to 48 inches, but can go as high as 56 inches, and can have at certain points compressors and valves to regulate flow. Centrifugal compressors are employed more frequently than reciprocating ones. Ball valves are also more common than butterfly ones. Distribution pipelines are smaller in diameter and typically do not have compressors, nozzles or valves.[540] Transmission pipelines are typically made of steel, while distribution pipelines can be made out of steel, iron and increasingly of polyethylene. Meters are another important component of gas networks.

Compressors are central parts of gas networks, serving to address pressure drops in transmission pipelines. Compressors can be combined in compressor stations housing several units. Pipeline gas transport as well as gas storage employ mainly centrifugal and reciprocating gas compressors, which can be used for baseload or peak compression. Compressor stations may house also scrubbers and filters which remove liquids and particle matter.[541,542] Compressor stations usually have multiple compressors in order to account for scheduled maintenance and unplanned outages.[543] Electric or dual-fuel (gas and electricity) compressors are being increasingly considered, to reduce maintenance needs, energy consumption and methane emissions[544]

Liquefied natural gas regasification terminals transform LNG to a gaseous state prior it is injected in the transmission network (or consumed on-site). Regasification terminals can be located onshore or offshore. Onshore terminals re-gasify LNG from a carrier docked on the site. The main components of an onshore terminal are unloading arms, piping (for liquid and gases), valves, LNG storage tanks (above or underground), compressors, pumps, re-condensers, and LNG vaporisers. Figure 5-35 presents a typical scheme for an LNG regasification terminal. Offshore terminals can be gravity-based structures, a concrete structure laying on the sea bottom, or be Floating Storage and Regasification Units (FSRU), LNG ships which offer flexibility for relocation but whose capacity is limited by the space available on-board. Both gravity-based structures and FSRU can be built elsewhere and moved to the installation site. [545] The main components of a FSRU are similar to those of an onshore terminal.

[540] Emenike et al. (2020). A review on energy supply chain resilience through optimization.
[541] White et al. (2019). Equipment Overview in Compression Machinery for Oil and Gas.
[542] Emenike et al. (2020). A review on energy supply chain resilience through optimization.
[543] American Gas Association. (2017). Downstream Natural Gas Supply Chain - Natural Gas System Resilience.
[544] May-Ostendorp et al. (2018). Electrifying Natural Gas - Opportunities for Beneficial Electrification and Load Flexibility in Natural Gas Pipeline Compressor Stations.
[545] Mokhatab et al. (2014). LNG fundamentals in Handbook of Liquefied Natural Gas.

Figure 5-35 Scheme of an onshore LNG regasification terminal[546]



Underground gas storage (UGS) sites provide large-scale storage to meet variations in demand and supply of natural gas, especially in the seasonal timeframe. The main reservoir types depleted oil and gas reservoirs, depleted aquifers, and underground salt caverns.[547] Depleted oil and gas fields are the most common reservoir type in Europe, although salt caverns and aquifers are also common.[548] As for pipeline compressor stations, UGS facilities can use reciprocating or centrifugal compressors, driven by gas engines, turbines or electric drives. Other components include piping, valves, and equipment for separation of solids and liquids, flow measurement, drying and heating. Underground tubular storage can also be employed for the storage of smaller gas quantities.[549]

The use of hydrogen and synthetic gases in the EU energy system is expected to increase significantly by 2050, while the demand for natural gas will conversely decrease. In the MIX scenario of the Climate Target Plan Impact Assessment, hydrogen and synthetic gases should account for 97 Mtoe, or 16% of total final energy consumption of the EU-27 in 2050.[550] Gas infrastructure can be employed to import, transport and storage hydrogen and synthetic gases, including by repurposing natural gas infrastructure. The European Commission's Hydrogen Strategy indicates that parts of the EU natural gas infrastructure can be repurposed for hydrogen, although further research is necessary. Nonetheless, EU gas network operators indicate that existing natural gas transmission pipelines require "need little modification to be fit for 100% hydrogen transport as the pipeline materials are generally fit for hydrogen transport", and that the repurposing costs amount to around 10-25% of the costs of building a new hydrogen pipeline.[551] Polyethylene pipes, which form around half of the European distribution pipelines, would also be fit for dedicated hydrogen distribution.[552] Three pure hydrogen underground storage facilities are already operational. Conversion of natural gas UGS to hydrogen would required adaptation. Storage in salt caverns has been demonstrated, while storage in depleted gas fields and aquifers is more difficult, with on-going research projects. The use of

[546] Mokhatab et al. (2014). LNG fundamentals in Handbook of Liquefied Natural Gas. Available at: https://ilng.ut.ac.ir/wp-content/uploads/2018/12/Dr.%20Mokhatab%20-%20Handbook%20of%20Liquefied%20Natural%20Gas%20-%20Main.pdf
[547] White et al. (2019). Chapter 9 – Midstream in Compression Machinery for Oil and Gas
[548] Gas Infrastructure Europe. (2018). Storage Map 2018. Available at: https://www.gie.eu/download/maps/2018/GIE_STOR_2018_A0_1189x841_FULL_FINAL.pdf
[549] DBI-GUT et al. (2008). Technical information about underground storage reservoirs for natural gas
[550] European Commission. (2020). Data of the graphs as presented in the impact assessment in support of the Commission Communication COM(2020) 562 final.
[551] Enagás et al. (2020). European Hydrogen Backbone – How a dedicated hydrogen infrastructure can be created. Available at: https://pgjonline.com/media/6906/2020_european-hydrogen-backbone_report.pdf
[552] Trinomics, LBST and E3M. (2020). Impact of the use of the biomethane and hydrogen potential on trans-European infrastructure. Available at: https://op.europa.eu/en/publication-detail/-/publication/10e93b15-8b56-11ea-812f-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=37085&WT.ria_f=3608&WT.ria_ev=search

existing natural gas infrastructure for transporting synthetic gases such as synthetic methane require no adaptations to the natural gas transport and storage infrastructure.[553]

The supply chain of gas infrastructure

Due to the number of equipment and components for gas networks, there is not a single overview of the entire supply chain.

An analysis of supply chain elements (summarised in Figure 5-36) was conducted to identify potentially vulnerable elements. The selection of the highly vulnerable elements is based on the assessment presented in the figure, but also on the literature review and stakeholder consultation. Some elements may appear to be highly vulnerable according to the assessment of these criteria, but for several other reasons (e.g. limited amount needed), both the literature and the stakeholders do not lead to the conclusion they should be considered as such. Therefore, these criteria (Figure 5-36) should only be considered as a preliminary assessment of the vulnerability of the elements, which is refined with other information sources.

Based on the analysis of the supply elements (detailed next and summarised in Figure 5-36), the following elements are identified as vulnerable: cyber security of control systems and 3rd-party services. Vulnerable elements are highlighted in bold in Figure 5-37, which presents an overview of the gas infrastructure fission supply chain.

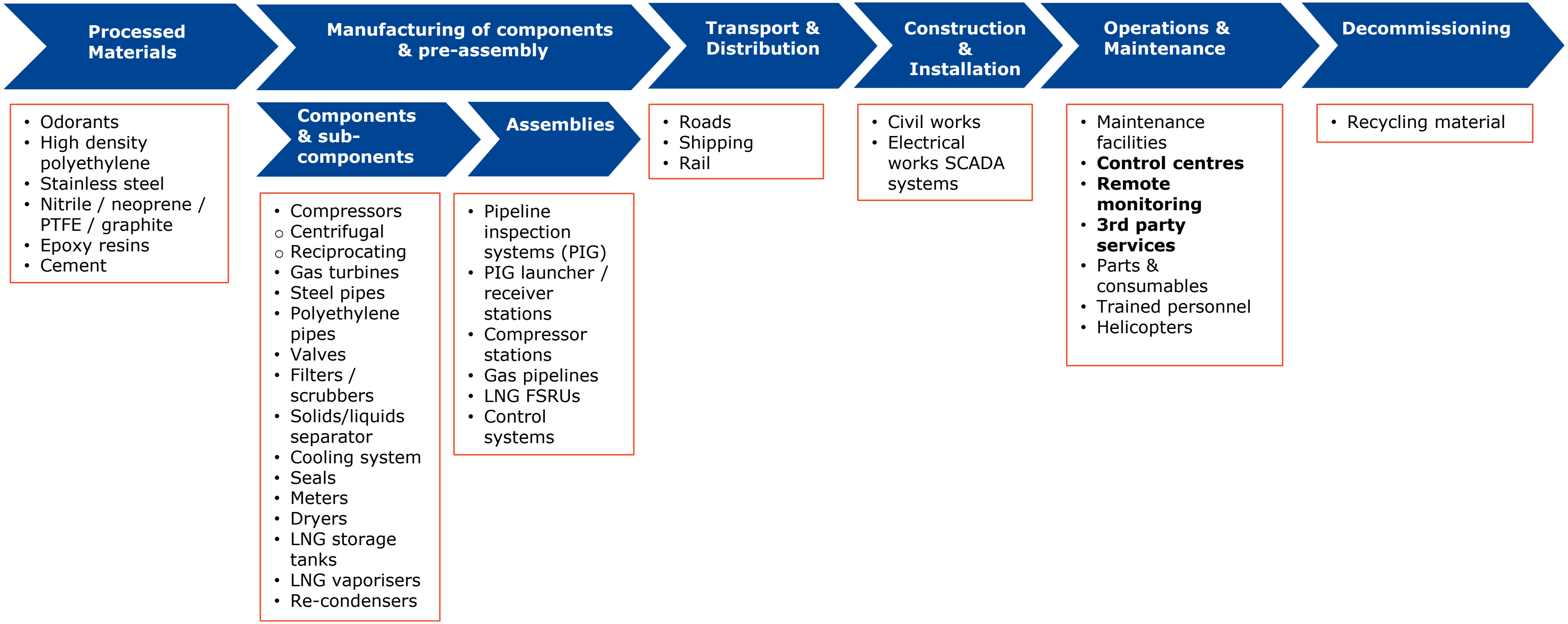
[553] Trinomics, LBST and E3M. (2020). Impact of the use of the biomethane and hydrogen potential on trans-European infrastructure ; Hydrogen Europe. (2019). Hydrogen Europe Vision on the Role of Hydrogen and Gas Infrastructure on the Road Toward a Climate Neutral Economy.

Figure 5-36 Vulnerabilities in the gas infrastructure supply chain

	Supply chain stage	Vulnerable element	Import dependency	Know-how/specialisation	Market concentration	Easy of substitutability	Price stability
			Import reliance	Patents share / other	CR4 / Main suppliers	Qualitative analysis	Coefficient of variation
Gas infrastructure	Raw / processed materials	Steel	21%	NA	44% (Extra-EU) (RU, TR, CN, UK)	NA	21%
		Epoxy resins (Bisphenol A)	46%	NA	~80% (Extra-EU) (KR, RU, SG, TW)	NA	NA
	Components / Equipment / Assembly	Compressors (reciprocating)	10%	NA	82% (Extra-EU) (CN, US, IN, UK)	NA	NA
		Compressors (turbo, single stage)	46%	NA	70% (Extra-EU) (UK, CN, CH, MX)	NA	NA
		Compressors (turbo, multistage)	30%	NA	82% (Extra-EU) (KR, CH, US, MX)	NA	NA
		Steel pipes (seamless)	<15%	NA	~75% (Extra-EU) (BR, UA, UK, CN)	ERW steel pipes	NA
		Gas meters	6%	NA	~93% (Extra-EU) (UK, TH, TR, CN)	NA	NA
		Fiters/purifiers	>90%	NA	~71% (Extra-EU) (UK, US, CH, TR)	NA	NA
		LNG/CNG containers	19%	NA	~82% (Extra-EU) (US, CN, UK, TR)	NA	NA
		LNG FSRU	High	Recent FSRUs developed by non-EU countries	NA	NA	NA
		Polyethylene pipes	6%	NA	~80% (Extra-EU) (CH, UK, CN, MK)	Steel/PVC/cast iron pipes	NA
		Gaskets	49%	NA	~69% (Extra-EU) (US, UK, CN, JP)	NA	NA
		Valves	~64%	NA	~82% (Extra-EU) (CH, UK, TR, CN)	NA	NA

Notes: CR4 – concentration ratio of 4 largest suppliers. Extra-EU – CR only for third country suppliers.
Extra-EU CR4 represents CR only for third country suppliers, given data availability. Therefore a high extra-EU CR4 may still not be rated as a vulnerability.
Sources: Eurostat PRODCOM/COMEXT; JRC. (2020). Study on the EU's list of Critical Raw Materials; other sources listed in section

Figure 5-37 The supply chain of gas infrastructure technologies[554]



*Note: vulnerable elements found highlighted in **bold**.*

554 Kumara et al. (2020). Electrical Characterization of a New Crosslinked Copolymer Blend for DC Cable Insulation.

The analysis of elements of the gas infrastructure supply chain, in particular vulnerable elements highlighted in bold in Figure 5-37, is detailed below.

Raw and processed materials

The main processed material relevant for gas infrastructure supply chains is steel. The EU was a net exporter of iron and steel in 2019 (led by Germany, Italy, Belgium and the Netherlands). Main non-EU suppliers comprise Russia, Turkey, China and the UK, totalling a CR4 of around 44% for imports from outside the EU.[555] There is also some reliance in the import of bisphenol A, an important resin for fusion-bound epoxy coating processes for natural gas pipelines, but without constituting a vulnerability. Rare earth elements are used in materials for storing hydrogen gas.[556]

Components manufacturing and preassembly

The EU is a net exporter of seamless steel pipes, generally used for high-pressure application such as gas transmission, with imports representing <20% of intra-EU consumption. Major exporters to the EU are the UK, Turkey, China and India. Seamless steel pipes are a component with multiple manufacturers worldwide, including ArcelorMittal (LU), ChelPipe (RU), EVRAZ (UK), JFE Steel Corporation (JP), Tenaris (LU), Vallourec (FR), Nippon Steel (JP) and Tianjin Pipe Corporation (CN). Imports are more significant for longitudinally-welded pipes (over 50% of intra-EU consumption), although the EU is still a net exporter. Exporters of longitudinally-welded pipes to the EU comprise Russia, Brazil, South Korea and Japan. Imports of polyethylene pipes represent only a small share (<10%) of the EU consumption.

A gas TSO also indicated that low quotas for third country imports for some pipeline elements (especially large diameter pipes) can lead suppliers to spread deliveries in order to maintain imports within quota limits (and thus have lower custom tariffs), leading to long delivery times. In 2019 the EU imposed definitive safeguard measures (import quotas) to certain steel products.[557] Orgalim, an association representing European technology industries, argued in June 2020 that a proposed review of the safeguards would restrict the flexibility of downstream steel European users, while the "impact of COVID-19 on production and demand in the EU steel market cannot yet be quantified".[558]

Major European centrifugal compressor manufacturers comprise Siemens (DE), MAN (DE), Nuovo Pignone (based in IT - owned by GE, US) Atlas Copco (SE), Ingersoll Rand (IE) and Burckhardt Compression (CH). Non-EU manufacturers comprise GE (US), Baker Hughes (US), Ariel Corporation (US).[559] The EU-27 is a net exporter of reciprocating compressors. Reciprocating compressor imports account for around only 10% of apparent consumption in the EU. COMEXT data indicates that the main exporters to the EU of reciprocating compressors are China, the US, India and the UK, with a CR4 of 82%.

EU imports of ball and plug valves respond for over 60% of apparent consumption, although common nomenclature codes (used by develop trade statistics) cover a wide range of valve types and sizes. Extra-EU supply is highly concentrated (CR4 >80%), with major suppliers being China, Switzerland, Taiwan and the UK. A central European gas TSO indicated that often semi-finished products have indeed to be imported from China to the EU, for example cast iron bodies for valve manufacturing.[560] Major valve manufacturers for oil & gas comprise Cameron (US), Emerson (US), Flowserve (US) and AVK (DK) – with thus an important concentration of US manufacturers, although Italian manufacturers may also be important to the oil & gas sector generally. [561]

EU gasket imports account for around 50% of apparent consumption, and while the EU is a net exporter by value, it is a net importer by quantity. Supply concentration from outside the EU is medium, with a CR4 of 69%, with the US, the UK, China and Japan as the main suppliers.

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555 Eurostat. (2020). International trade in goods by type of good.
556 NATO Energy Security Center of Excellence. (2020). Energy Security: Operational Highlights. Available at: https://enseccoe.org/data/public/uploads/2020/03/nato-ensec-coe-operational-highlights-no13.pdf
557 Commission implementing regulation (EU) 2019/159 imposing definitive safeguard measures against imports of certain steel products
558 Orgalim. (2021). Letter on the Review of the safeguard measures against imports of certain steel products. Available at: https://orgalim.eu/position-papers/trade-letter-safeguard-measures-against-imports-certain-steel-products
559 Mondor Intelligence. (2020). CENTRIFUGAL COMPRESSOR MARKET - GROWTH, TRENDS, COVID-19 IMPACT, AND FORECASTS (2021 - 2026). Available at: https://www.mordorintelligence.com/industry-reports/global-centrifugal-compressors-market-industry
560 Direct communication with the TSO.
561 Euractiv.com. (2020). Coronavirus creates repair headache for oil and gas industry. Available at https://www.euractiv.com/section/energy/news/coronavirus-creates-repair-headache-for-oil-and-gas-industry/

A more vulnerable element for gas infrastructure appears to be filters and purifiers. PRODCOM data indicates a high import reliance in the category (>90%), although the category is broad ("Machinery and apparatus for filtering and purifying gases (other than air)"). Nonetheless, this indicates a high dependence, with major suppliers to the EU being located in the UK, US, CH and TR – with a CR4 of 71%. Global market leaders of industrial filtration elements include Danaher (US) and Donaldson (US).[562]

Tens of LNG re-gasification terminals have been constructed in the last few years or are scheduled for commissioning until 2023. The majority is located in Asia, but Poland and France commissioned new terminals since 2015, Croatia's terminal was commissioned in January 2021, and Finland and Cyprus should commission others in 2021.[563] SNC-Lavalin (CA) designed the polish terminal, and SENER (ES) and TECHint (IT-AR) the French one. The Croatian FSRU was constructed by converting a LNG transport ship in a Chinese shipyard.[564] The Cypriot FSRU is also being built by a Chinese-led consortium.[565] Most LNG vessels are currently built by South Korean or Chinese shipyards.[566]

Underground gas storage sites were being constructed in 2018 in the Czech Republic, Germany, Italy, Poland and Portugal. Generally, these facilities have been designed by EU companies (such as Bilfinger Tebodin, Saipem, Control Process), usually of the same Member State as of the site itself.

Concerning hydrogen infrastructure technology, the US is the leader in hydrogen transport pipelines, with over 2 600 km around 2016. Europe has the second longest hydrogen network, with around 1 600 km in 2016. The main companies operating hydrogen networks in Europe are Air Liquide (FR), Air Products (US) and Linde (DE-US). Both Air Liquide and Linde have engineering divisions providing services to the group but also to third parties, including for the design of LNG terminals in the case of Linde. Furthermore, Air Liquide operates the third longest hydrogen network in the US (545 km in 2016), after Praxair (US) and Air Products.[567] The only hydrogen storage site in Europe is located at Teeside (UK).[568]

Operation and maintenance

Risk assessments for natural gas pipelines usually focus on gas commodity supply risks. In recent years increased attention has been put in increased bi-directionality in EU gas transmission pipelines, in order to increase the security of gas supply especially for Eastern EU Member States[569], as lack of bi-directionality can exacerbate supply dependencies.

A group of European gas TSOs collaborate in the European Gas Pipeline Incident Group (EGIG) to collect data on gas pipeline incidents. The latest report indicates that the most frequent causes for failures in pipelines in the 2007-2016 period comprise external interference and corrosion, with ground movement and construction defects / material failure being other relevant causes.[570]

Dependence on spare parts to address planned and unplanned maintenance requirements is a potential vulnerability given the supply chain for the main components such as pipelines, compressor parts and other elements (valves, gaskets) is integrated. However, gas TSOs deem the global market sufficient diverse and have not indicated the supply of parts to be a particular concern. Moreover, alternative suppliers for e.g. compressor parts exist, providing more options than just the original equipment manufacturers. Terrorism is also identified as a relevant risk for pipelines[571], although studies in this aspect and the connections to the gas pipeline supply chains not available.

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562 Markets and Markets. (2020). Industrial Filtration Market.
563 International Gas Union. (2020). World LNG Report 2020.
564 Offshore Energy. (2020). Croatia's first FSRU delivered. Available from: https://www.offshore-energy.biz/croatias-first-fsru-delivered/
565 Hellenic Shipping News Worldwide. (2020). Cyprus enters LNG era with FSRU groundbreaking at Vassilikos. Available at: https://www.hellenicshippingnews.com/cyprus-enters-lng-era-with-fsru-groundbreaking-at-vassilikos/
566 International Gas Union. (2020). World LNG Report 2020.
567 Hydrogen Analysis Resource Center. (2016). Hydrogen Pipelines Database. Available at: https://h2tools.org/hyarc/hydrogen-data/hydrogen-pipelines
568 Tarkowski, R. (2019). Underground hydrogen storage: Characteristics and prospects. Available at: https://doi.org/10.1016/j.rser.2019.01.051
569 For example, EU Parliament report identified as recently as 2009 reverse flow capabilities as an issue. Pedersen et al. for the EP Policy Department A (2009) An Assessment of the Gas and Oil Pipelines in Europe.
570 European Gas Pipeline Incident Data Group. (2018). 10th Report of the European Gas Pipeline Incident Data Group (period 1970 – 2016). Available at: https://www.egig.eu/startpagina/$61/$108
571 Pedersen et al. for the EP Policy Department A (2009) An Assessment of the Gas and Oil Pipelines in Europe: Briefing Note. Available at: https://www.msp-platform.eu/sites/default/files/gas_and_oil_pipelines_in_europe_en.pdf

The operation of natural gas infrastructure is also an important aspect, relying especially in SCADA systems and highly-skilled operators. SCADA systems monitor parameters such as flow rate and pressure through remote sensors, with automatic leak detection mechanisms in place.[572] Recently increased attention has been paid to cybersecurity of gas infrastructure. [573] As for the electricity system, gas infrastructure control systems could be compromised through ITC service providers, unintentional vulnerabilities or backdoors added in equipment during the design, manufacturing or shipping stages. Actions to address this risk are being taken in the US.[574] German gas TSOs indicate that, in the scope of the ISO/IEC 27001 standard on information security, there are supplier control mechanisms for cyber security.

Evidence of short-term vulnerability to the COVID-19 pandemic

In 2020, due to the arrival of LNG shipments and reduced energy demand due to the COVID-19 crisis and price reductions, higher volumes of natural gas were stored in the EU. [575] Gas network operators were able to maintain normal operation despite constraints placed by COVID.[576] ENTSOG developed a document to share best practices of gas network operators relating to general actions, dispatching centres, base camps (i.e. on-site accommodation) and remote control. Measures taken by gas network operators are to a large extent similar to those taken by electricity network operators (described in the respective supply chain fiche) and summarised in the Commission document of good practices for assuring energy security in the face of pandemics.[577]

Manufacturing and trade disruptions due to COVID-19 have affected the gas transport and also the overall oil & gas industry globally, including due to difficulties in e.g. manufacturing and export of Italian valves.[578] While in the future COVID-19 may impact specific component supply chains and regions, it is impossible to determine which exactly.[579]

Generally, European gas TSOs experienced limited disruptions only and indicated no major risks in the short-term (i.e. for the 2020/2021 winter). While all TSOs had to take measures to ensure the safe operation of the system and their construction and maintenance projects, very few saw important disruptions in their supply chains. Some suppliers were experiencing important cash flow issues – gas TSOs can sometimes provide more favourable terms and conditions (such as shorter payment terms) to support them. Others have internalised the additional costs associated with the pandemic in the new prices when contracts were renegotiated. In one occasion, a gas TSO purchased from another TSO a spare part which could not be sourced. However, in most cases difficulties have not led to important disruptions.

Three German TSOs indicated that supply chains for ancillary technologies and services can be seen as resilient. Most of the maintenance work in the country is done by workers from the country or other EU Member States. Nonetheless, increased transportation times was observed by a German TSO depending on the location of the suppliers and measures taken in their countries. Nonetheless, this TSO has indicated that the global supply chain is diversified enough to hedge against disruptions in specific regions.

A central European gas TSO reported significant difficulties in the supply chain of pipeline components in March and April 2020, due to disruptions in manufacturing in Central and Western Europe. In November the TSO observed again an increase in delivery delays. Another obstacle is the difficulty in conducting quality controls in suppliers' sites by own staff or third-party certifiers. Another gas TSO reported that some suppliers went bankrupt, requiring that others be found.

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572 About Pipelines. (2014). Pipeline control rooms and safety. Available at: https://www.aboutpipelines.com/en/blog/pipeline-control-rooms-and-safety/

573 For example ENTSOG and GIE. (2019). Cyber Security TF. Available at: https://www.ceer.eu/documents/104400/-/-/2c424b85-e79a-13b4-6265-a7eb0c6dc8c1
CEER. (2018). CEER Cybersecurity Report on Europe's Electricity and Gas Sectors. Available at: https://www.ceer.eu/cybersecurity-report-on-europe-s-electricity-and-gas-sectors.

574 Public-Private Analytic Exchange Program. (2017). Supply Chain Risks of SCADA/Industrial Control Systems in the Electricity Sector: Recognizing Risks and Recommended Mitigation Actions.

575 ACER. (2020). Market Monitoring Report 2019 – Gas Wholesale Market Volume. Available at: https://documents.acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/ACER_Market_Monitoring_Report_2019-Gas_Wholesale_Markets_Volume.pdf

576 As confirmed by a survey of websites of Fluxys, Gasunie, Terega, GRTgaz, SNAM, FGSZ.

577 European Commission. (2020). SWD(2020) 104 final. Energy Security: Good Practices to Address Pandemic Risks.

578 Euractiv.com. (2020). Coronavirus creates repair headache for oil and gas industry. Available at https://www.euractiv.com/section/energy/news/coronavirus-creates-repair-headache-for-oil-and-gas-industry/

579 Also for Energy Community Parties. See Energy Community. (2020). COVID-19: Security of energy supply monitoring. Available at: https://www.energy-community.org/dam/jcr:587ca5c4-156e-4ca3-994c-7b93eae71fb7/COVID-19_Security_of_energy_supply_monitoring.pdf

Gasunie identified issues in the parts supply chain from China and India, highlighting it as an uncertainty factor for the construction of the nitrogen factory Zuidbroek (necessary for converting H to L gas due to the phasing out of the Groningen gas field), although the target commissioning date of April 2022 was deemed feasible. The FCH JU approval of a subsidy request for the HEAVENN hydrogen valley was also delayed due to COVID-19, and other factors. Gasunie's construction projects have in general continued with more strict safety guidelines.[580]

A gas TSO operators has indicated that measures taken by national or regional governments were not always clear and transparent, also as a consequence of the fast changing situation which required quick adaptation. This increased the coordination efforts gas network operators had to take to ensure that foreign service providers were able to travel, stay and be tested. The Commission noted that for certain key installations such as offshore platforms and LNG plants, 'pre-confinement of staff before accessing premises and action plans, including early detection and evacuation measures, was put in place'.[581]

Table 5-5 Main impacts of COVID-19 on the gas infrastructure supply chain and measures taken

Supply chain stage	Challenge(s) encountered	Short/long-term adaptation measures
Components & sub-components	Meeting of contractual delivery deadlines	Crisis communication and coordination rules
Transport & distribution	Rarely, difficulties in importing parts from e.g. China and India	Supply source diversity; monitoring of essential suppliers and service providers; material exchange of critical components between TSOs (if possible); stock of specific components (if possible)
Construction & installation	Delays in construction schedules. Response times from contractors and authorities may take longer	Early coordination and exchange between parties; stock of specific components (if possible)
Operations & maintenance	Social distancing / difficulties in employee commutes / impossibilities to travel for international suppliers	Enhanced safety measures for control centres operators / field teams; maintenance is usually planned well in advance (publication of maintenance plan)

Impacts in the medium-term due to difficulties in the supply chain could possibly arise due to prolonged measures (over 6 months) such as lockdowns or closure of borders, although it is impossible to assess the likelihood of such scenario. Such measures would impact the capacity to conduct inspections of suppliers, the maintenance services provided by foreign contractors, and the import of parts and materials. The following table summarises the main impacts of COVID-19 and measures taken as indicated by European gas TSOs.

Several gas network operators indicate to have a business continuity plan, such as Teréga, Gasunie and Enagás. Maintenance activities were eventually resumed for e.g. GRTgaz, after being halted at the start of the crisis.[582] Administrative staff of multiple operators are also working from home, such as from Teréga, OGE and SNAM. SNAM has built a makeshift accommodation for its control centres operators.[583] Gas network operators maintain also stocks of critical components. A German TSO noted that its stock of components was not affected by the pandemic, also due to their activities being classified as essential, which allowed suppliers to maintain their deliveries to construction sites and warehouses.

Suggested policy measures which could be taken to address supply chain vulnerabilities and the impact of COVID-19 include:

- Use of predictable and transparent measures to address COVID-19, with sufficient flexibility to account for new developments
- Assuring the cross-border movement of products and personnel providing services to essential sectors;
- Appropriate analysis of the impacts to EU manufacturing and downstream users of products subject to import quotas, considering the impacts of COVID-19 on supply and demand

[580] Gasunie. (2020). Halfjaarbericht 2020. Available (in Dutch) at: https://www.gasunie.nl/nieuws/halfjaarbericht-2020
[581] European Commission. (2020). SWD(2020) 104 final. Energy Security: Good Practices to Address Pandemic Risks.
[582] GRTgaz. (202`). COVID-19. Available at: https://www.grtgaz.com/en/medias/article/covid-19
[583] SNAM. (n.d.). COVID-19: SNAM's Initiatives. Available at: https://www.snam.it/en/Media/COVID-19/

Moreover, measures which can be taken by gas network operators include:

- Diversification of supply sources
- Monitoring of essential products and service providers
- Identification and stocking of critical components
- Exchange of components between gas TSOS
- Exchange of best practices between gas TSOs

5.8. Electricity networks

Introduction and technology description

Electricity networks can be schematised as links and nodes. Transmission and distribution lines operating at a certain voltage are the links, which serve to connect the nodes, where substations may be located if changes in voltage are necessary.

Electricity networks can operate in direct-current (DC) or alternate-current (AC). AC electricity systems operate at a particular frequency (50 Hz for the synchronous areas in Europe). There are five synchronous areas in Europe (Continental Europe, Nordic, Baltic, Great Britain, and Ireland-Northern Ireland).[584] AC transport is generally more economically advantageous due to the facility in changing voltage levels with transformers, but losses strongly increase with distance for underground/submarine cables, in which case DC transport can be more economic from a certain capacity and distance threshold due to lower cable capacitance and thus losses.[585]

Flows in an AC or DC meshed grid (i.e. with 'parallel' lines) cannot be fully controlled due to Kirchhoff's laws, which means the total electricity flow will be distributed between the different possible paths. Flows can be controlled with AC/DC converters (which can be used to form DC/DC 'back-to-back' converters) or with AC phase shifters.

The main components of electricity lines are cables and conductors. Electricity transmission lines can be overhead, in which case conductors are not insulated, or underground, where cables are insulated. Cables and conductors are made of copper or more frequently aluminium, while the most common insulation methods are extruded cross-linked polyethylene (XLPE) or mass-impregnated cables. In addition, to cables and conductors, transformers and AC/DC converters, the other main components comprise switchgears, tower, pylons and insulators, and SCADA (supervisory control and data acquisition) systems.[586]

The supply chain of electricity networks

Due to the number of equipment and components for electricity networks, there is not a single overview of the entire supply chain. The main elements per supply chain stages are indicated in the Figure 5-39.

An analysis of supply chain elements (summarised in Figure 5-38) was conducted to identify potentially vulnerable elements. The selection of the highly vulnerable elements is based on the assessment presented figure 5-38, but also on the literature review and stakeholder consultation. Some elements may appear to be highly vulnerable according to the assessment of these criteria, but for several other reasons (e.g. limited amount needed), both the literature and the stakeholders do not lead to the conclusion they should be considered as such.
Therefore, these criteria (Figure 5-38) should only be considered as a preliminary assessment of the vulnerability of the elements, which is refined with other information sources.

Considering this, the following elements are identified as vulnerable: magnesium, silicon metal, electrical steel, and cyber security of control systems and 3rd-party services. Vulnerable elements are highlighted in bold in Figure 5-39, which presents an overview of the electricity networks supply chain.

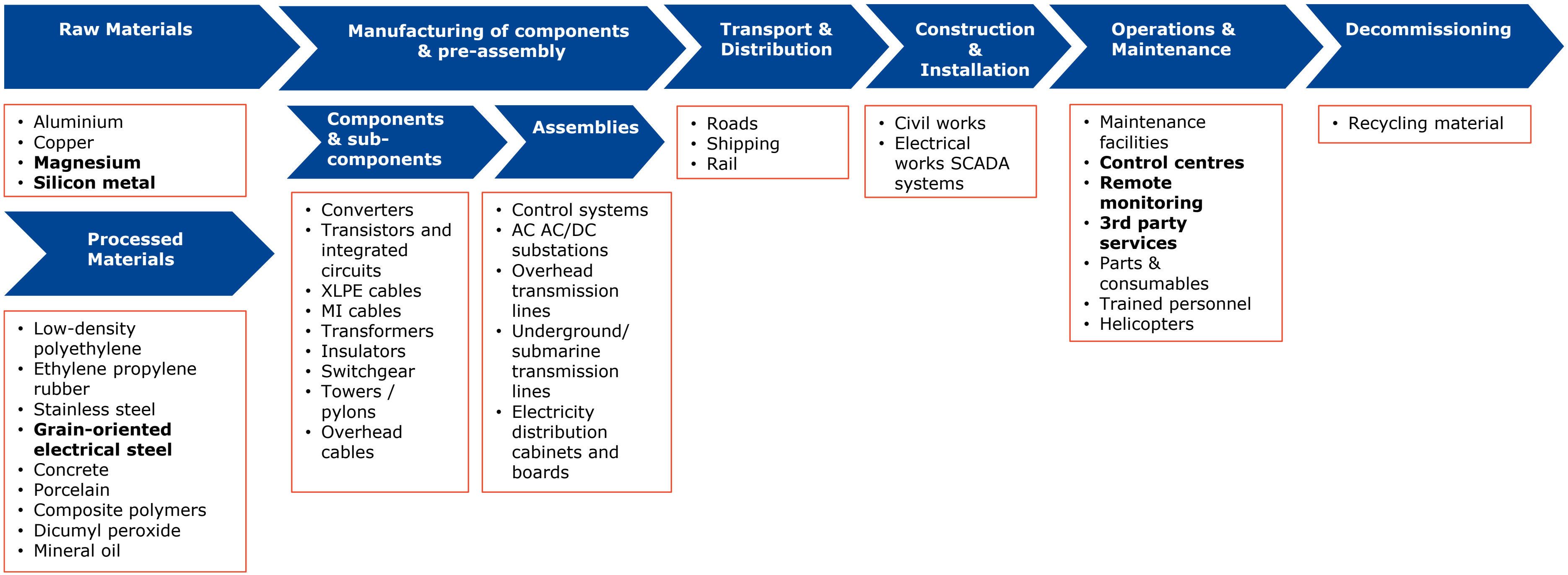
[584] ENTSO-E. (n.d.). System Operations Committee. Available at: https://www.entsoe.eu/about/system-operations/
[585] Cretì et al. (2019). Electricity Systems and the Electricity Supply Chain in Economics of Electricity.
[586] Ibid.

Figure 5-38 Vulnerabilities in the electricity networks supply chain

	Supply chain stage	Vulnerable element	Import dependency	Know-how/specialisation	Market concentration	Easy of substitutability	Price stability
			Import reliance	Patents share / other	CR4 / Main suppliers	Qualitative analysis	Coefficient of variation
Electricity networks	Raw materials	Aluminium	59%	NA	43% (RU, DE, MZ, FR)	Medium, by copper	22%
		Copper	44%	NA	58% (PL, CL, PE, ES)	Medium, by Aluminium	42%
		Magnesium	100%	NA	96% (CR3) (CN, US, IL)		~10% (4 years)
		Silicon metal	63%	NA	68% (NO, FR, CN, BR)	Low	~10-15% (4 years)
	Processed materials	Low-density polyethylene	35%	NA	65% (Extra-EU) (SA, UK, KR, US)	EPR P-laser technology	NA
		Grain-oriented electrical steel	32% Higher for high-permeability	NA	94% (Extra-EU) (RU, JP, CN, CH)	Lower permeability GOES Amorphous steel	NA
		Concrete	~0-5%	NA	NA	NA	NA
		Bismuth	50%	NA	93% (CN, BE, LA, MX)	NA	NA
		Stainless steel	42% (tubular) Net importer in 2018	NA	44% (Extra-EU) (RU, TR, CN, UK)	NA	21%
	Components / Equipment / Assembly	Converters	Net exporter in 2018	High CN leads MT HVDC	>80% (VSCs) (DE, CH, US)	NA	NA
		Insulated cables	<20%	High	~60% (Extra-EU) (KR, CH, CN, US)	NA	NA
		Transformers	Net importer	<5% of global patents	~80% (Extra-EU) (CN, CH, KR, TR)	NA	NA
		Insulators	40% Net exporter in 2018	NA	~80% (Extra-EU) (CN, US, IN, CH)	NA	NA
		Aluminum wires	27%	NA	~93% (Extra-EU) (TR, CN, IN, KR)	NA	NA
		Cabinets, boards and other	Net exporter in 2018	NA	60-80% per equip. (CN, US, KR, JP)	NA	NA
		HV circuit brakers	21% Net exporter in 2018	~ 5% of global patents (DC breakers)	~70% (Extra-EU) (UK, TR, CH, CN)	NA	NA
		HV isolating switches	40% Net exporter in 2018	NA	~90% (Extra-EU) (CH, CN, UK, US)	NA	NA
		Power electroniics / valves	EU companies have ~40% of global market	~10% of global patents	~75% (CH, DE, CN, US)	NA	NA
		HV fuses	40% (tubular)	NA	~80% (Extra-EU) (UK, CN, US, TR)	NA	NA

Notes: MT HVDC – multiterminal HVDC; VSC – voltage source converter.
Extra-EU CR4 represents CR only for third country suppliers, given data availability. Therefore a high extra-EU CR4 may still not be rated as a vulnerability.
Sources: Eurostat PRODCOM/COMEXT; JRC. (2020). Study on the EU's list of Critical Raw Materials; European Commission. (2020). Report on progress of clean energy competitiveness. COM(2020) 953; FastMarkets for price data of certain raw materials; Federal Reserve Bank of St. Louis. (2020). FRED – Producer Price Index by Commodity: Metals and Metal Products: Steel Mill Products; other sources listed in section.

Figure 5-39 The supply chain of electricity network technologies[587]



*Note: vulnerable elements found highlighted in **bold**.*

[587] Own elaboration and Kumara et al. (2020). Electrical Characterization of a New Crosslinked Copolymer Blend for DC Cable Insulation.

The analysis of **elements of the** electricity networks **supply chain, in particular vulnerable elements highlighted in bold in** Figure 5-39**,** is detailed **below.**

Raw and processed materials

The main raw materials for the supply chain are the aluminium and copper employed in the cable manufacturing. Neither is included in the 3rd EU list of critical raw materials, as they are ranked with a high economic importance but low supply risk. However, magnesium and silicon metal, also employed, are considered critical raw materials.[588]

The main processed materials are employed in the manufacturing of the cables, insulators and towers, and transformers. PRODCOM data indicates an import dependency for low-density polyethylene (used for developing XLPE cables) of around 35% as shown below. Transformer mineral oil insulation and coolant could become critical materials in the future but are not assessed so at the moment by the industry.

The main processed materials for transformers manufacturing include mineral oil, paper, cold steel and hot steel. Transformer manufacturing also employs domain-refined high-permeability grain-oriented electrical steel (GOES). This premium type of GOES reduces electrical losses, allowing to reduce transformer size, which can be very important in certain applications (such as in the nacelles of wind turbines), as well as increasing energy efficiency and reducing resource use.

Tier 1 ecodesign efficiency requirements for transformers came into force in 2015, and stricter tier 2 requirements will come into force in July 1st 2021.[589] The impact assessment for the ecodesign regulation[590] found there were four GOES manufacturers in the EU (ThyssenKrupp Electrical Steel, Orb Electrical Steels, ArcelorMittal Frydek Mistek, Stalprodukt) and eight outside of the EU NLMK (RU), Nippon Steel (JP), JFE (JP), AK Steel (US), ATI (US), Baosteel (CN), Wisco (CN), Anshan (CN), Posco (KR), and ArcelorMittal Inox (BR). The impact assessment estimated that the market share of EU transformer manufacturers was likely to increase due to product innovation and the relative decrease of the share of labour inputs to copper and magnetic steel inputs.

In 2015 the European Commission imposed anti-dumping tariffs on grain-oriented electrical steel from China, Japan, South Korea, Russia and the US.[591] The supporting investigation found that 'Union producers have been investing in the production of high permeability types', even in face of challenging economic conditions to which dumping practices by the concerned trade partners contributed. The investigation also found that the capacity for EU suppliers to meet demand for high-permeability electrical steel in the EU worsened after the entry into force of the tier 1 of the transformers ecodesign regulation. It also stated that 'the Commission cannot foresee whether the EU producers will achieve the quality and capacity to serve the needs of the EU users in the foreseeable future, in particular concerning the availability of some types of the high-permeability GOES.' However, 'to foster an industrial policy is not the objective of an anti-dumping investigation though; it only aims at a return to conditions of fair competition between the Union and exporting producers.'

In 2020 the Commission started an Expiry Review on the anti-dumping measures, which extend them until the conclusion of the review. The summary of the Expiry Review request[592] argues that the EU GOES industry may still be affected by dumping and anti-dumping bypass measures from competitors and highlights the strategic importance of GOES and that the capacity of EU suppliers for this GOES type can satisfy only a small share of the forecasted EU demand, especially for the highest permeability grades. The investigations for the 2015 measures corroborate that EU supply is insufficient to satisfy the demand for high-permeability GOES. The number of EU suppliers for grain-oriented electrical steel have fallen due to closure of Tata Steel (Orb Electrical Steel).

[588] JRC. (2020). Study on the EU's list of Critical Raw Materials. Available at: https://ec.europa.eu/jrc/en/news/jrc-assesses-critical-raw-materials-europe-s-green-and-digital-future
[589] Commission Regulation (EU) No 548/2014 on implementing Directive 2009/125/EC with regard to small, medium and large power transformers.
[590] Impact Assessment accompanying the Draft Commission Regulation implementing Directive 2009/125/EC with regard to small, medium and large power transformers. SWD(2014) 162
[591] Commission Implementing Regulation (EU) 2015/1953 imposing a definitive anti-dumping duty on imports of certain grain-oriented flat-rolled products of silicon-electrical steel originating in the People's Republic of China, Japan, the Republic of Korea, the Russian Federation and the United States of America.
[592] Executive Summary of the expiry review request concerning imports of grain-oriented flat-rolled products of silicon-electrical steel ("GOES") originating in the People's Republic of China, Japan, the Republic of Korea, the Russian Federation and the United States of America

There is some EU R&D support to GOES, for example through the H2020 project ESSIAL[593] (Electrical Steel Structuring, Insulating and Assembling by means of the Laser technologies), part of the H2020 Technologies for Factories of the Future, as well as ALEM (Additional Losses in Electrical Machines). Given the strategic importance of the steel industry, the Commission published in 2013 an "Action Plan for a competitive and sustainable steel industry in Europe".[594] More recently, the main EU industrial policy instruments are the New Industrial Strategy for Europe,[595] which led to the creation of the Industrial Forum, and the Important Projects of Common European Interest, whose strategic forum identified low-CO2 emission industry as one of the six strategic value chains. Furthermore, a EU Strategy on Clean Steel was announced with the New Industrial Strategy.

Components manufacturing and integration

AC/DC converters, cables, conductors, transformers and switchgear are the main elements in the manufacturing stage for electricity networks.

DG COMP[596] published a decision regarding a competition case concerning the acquisition by the Italian power cable manufacturers Prysmian of the North-American General Cable. The analysis of the market shares of global manufacturers indicates that Prysmian, General Cable and Nexans (a French company) had over 50% of the EEA market share for different cable classes in 2016 (HV/EHV underground, LV/MV and HV/EHV submarine cables). NKT cables (a Danish company) is generally the following largest manufacturer after Prysmian, General Cable and Nexans. In 2019 the industry association Europacable assessed that the manufacturing capacity of European cable manufacturers would be sufficient to match the forecasted demand for submarine cables considering the ENTSO-E's TYDNP 2018.[597] The EU had an important reliance of 27% for aluminium wires in 2018, a category which includes aluminium-conductor steel-reinforced cables - the main wire type for overhead lines. While the EU is a net importer for that element, it is not identified as a vulnerability.

The 2013 impact assessment for the Directive on the Eco-design Requirements for Power, Distribution and Small Transformers[598] indicates that the EU in 2004-2007 imported most of its transformers, being a net importer for all transformer types. The main European manufacturers (Siemens, ABB, CG Power System, and Schneider Electric)[599] are important global players. The EU is a net exporter of ceramic and glass insulators and related components.[600]

AC/DC converters are mostly used for long-distance HVDC power transmission, being employed in the EU particularly for connecting offshore wind farm distant from shore and for submarine interconnectors. A technology with growing use are voltage-source converters (VSC), whose supply is highly concentrated, with the main converter manufacturers of offshore HVDC converter stations in the EU being ABB and Siemens. However, there are no specific bottlenecks identified for VSCs.[601] The PRODCOM data does that there is a certain dependency on static converters imports, which equal the EU-27 production in value, but this comprises a larger range of converter types and sizes. Moreover, China is a leader in the development and deployment of multivendor multiterminal HVDC systems,[602] which would be necessary for the development of an offshore grid.
Other elements such as cabinets & boards, power electronics and switchgear do not constitute a particular vulnerability. Companies such as Hitachi ABB (JP/SE/CH) and Siemens (DE) retain strong market shares, along non-EU companies such as China XD (CN), NR Electric (CN) and General Electric (US). Compared to the US and especially Asian countries, the EU does have a very low share of global patents for several elements, including power electronics.[603] Stakeholders have also not indicated any particular vulnerability related to the manufacture or installation of electricity transmission towers and pylons.

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[593] CORDIS. (n.d.). Electrical Steel Structuring, Insulating and Assembling by means of the Laser technologies. Available at: https://cordis.europa.eu/project/id/766437
[594] European Commission. (2013). SWD(2013) 407. Action Plan for a competitive and sustainable steel industry in Europe.
[595] European Commission. (2020). COM(2020) 102 final. A New Industrial Strategy for Europe. COM/2020/102 final, updated in May 2021. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0102
[596] DG COMP. (2018). Case M.8770 - PRYSMIAN / GENERAL CABLE.
[597] EUROPACABLE. (2019). Demand and Capacity for HVAC and HVDC underground and submarine cables
[598] Aníbal et al. (2013). Impact Assessment Implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign Requirements for Power, Distribution and Small Transformers.
[599] Coté et al. (2018). Market Analysis of the Offshore Wind Energy Transmission Industry.
[600] CEPS et al. for DG GROW. (2017). Cumulative Cost Assessment (CCA) of the EU Ceramics Industry. CEPS et al. for DG GROW. (2017). Cumulative Cost Assessment (CCA) of the EU Glass Industry.
[601] Coté et al. (2018). Market Analysis of the Offshore Wind Energy Transmission Industry.
[602] DG ENER. (2020). Workshop: Horizon 2050 power system and the role of HVDC technologies in a highly decentralised RES generation
[603] European Commission. (2020). COM(2020) 953. Report on progress of clean energy competitiveness.

Operation and maintenance

The ENTSO-E and Europacable highlighted in 2019 the need to improve the reliability and availability of HVDC cables and systems, noting that while advances were made in the last years, further improvement could be made, as HVDC systems are "strategic assets within high voltage electricity transmission networks, [and] their availability is therefore considered essential", not only due to the impact of eventual outages but also to the system benefits that these system provide.[604]

With the increase of renewable electricity generators and HVDC transmission in the power system, there is a risk that there is not sufficient system inertia to withstand large disturbances (e.g. disconnection of a large generator), leading to significant frequency deviations or even a black-out. The ASSET project has nonetheless concluded that, at least until 2030, there "remains enough inertia in the system to cope with imbalance which are much higher than the current reference incident".[605]

A detailed analysis of cybersecurity issues is included in the analysis of the supply chain of digital technologies for the energy sector. Cybersecurity of the electricity system is an important concern, which is recognised by the European Commission in its 2019 recommendation[606], which highlights the need for a sectoral approach due to "real-time requirements, a mix of advanced and legacy technologies, and the cascading effects of disruptions".[607] A cybersecurity network code for electricity is being drafted[608] and in May 2020 ENTSO-E announced it had identified a cyber intrusion in its network.[609] Even though this refers to ENTSO-E's IT rather than the TSOs' OT system, it illustrates the increasing number of cyber-threats to energy infrastructure. Cyber- and overall electricity system security is not only relevant to the EU but to European countries in general (and even Morocco, Algeria and Tunisia) which are part of the continental European synchronous area. The 2019 Regulation on risk-preparedness in the electricity sector[610] requires the ENTSO-E to submit to ACER a methodology for identifying regional electricity crisis scenarios, including cyber threats.

Evidence of short-term vulnerability to the COVID-19 pandemic

The following table summarises the main impacts of COVID-19 on the electricity networks supply chain as well as measures taken.

[604] ENTSO-E and Europacable. (2019). Recommendations to improve HVDC cable systems reliability.
[605] Tielens et al. for DG ENER. (2018). Penetration of renewables and reduction of synchronous inertia in the European power system – Analysis and solutions.
[606] European Commission. (2019). Recommendation (EU) 2019/553 on cybersecurity in the energy sector.
[607] European Parliamentary Research Service. (2019). Briefing - Cybersecurity of critical energy infrastructure.
[608] ENTSO-E. (2020). Annual Work Programme 2020. Available at: https://eepublicdownloads.entsoe.eu/clean-documents/Publications/ENTSO-E%20general%20publications/200217_ENTSO-E_Annual%20Work%20Programme%202020%20(final).pdf
[609] ENTSO-E. (2020). ENTSO-E has recently found evidence of a successful cyber intrusion into its office network. Available at: https://www.entsoe.eu/news/2020/03/09/entso-e-has-recently-found-evidence-of-a-successful-cyber-intrusion-into-its-office-network/
[610] Regulation (EU) 2019/941 on risk-preparedness in the electricity sector

Table 5-6 Main impacts of COVID-19 on the electricity networks' supply chain and measures taken

Supply chain stage	Challenge(s) encountered	Short/long-term adaptation measures
Raw Materials	Availability of metal components for cable accessories and specific compounds	-
Processed Materials	Availability of processed materials; Cash availability; Renegotiation of Existent Contracts / contract clauses not covering pandemics fully	Develop alternative suppliers, monitor single source supplies Improve suppliers/materials redesign qualification processes, including with use of remote qualification Designation as essential activity
Components & sub-components	Availability of components and Sub-components; Cash availability; Contracts renegotiation	
Assembly/ manufacturing	Cross-border mobility of support workers (technology)	New working shifts/ teams and facilities adaptation
Transport & distribution	Availability of suppliers for cable deliveries in high-infection areas; Safety protocols for (un)loading in cable factories	Maintain multiple transport providers Dedicated team to address logistics Strong protocols at factory level
Construction & installation	Cross-border mobility of workers Differences in national measures Lack of testing capacity	Local workforce contracting (mainly in non-EU countries)
Operations & maintenance	Health safety measures in control Centres and maintenance Cross-border mobility of workers	Designation as essential activity Optimise process
Decommissioning	Cross-border mobility of support workers	-

T&D Europe notes that at least France, Germany and Spain have included the "manufacturing of electric motors, generators, transformers and electricity distribution and control apparatus (NACE 27.1)" in the list of essential activities, thus reducing the impact of mitigation measures to the COVID-19 crisis.[611]

COVID-19 has led the European cable industry to significantly strengthen their business continuity plans. For cables, the majority of raw materials suppliers are located in the EU itself. Hence, closure of intra-EU borders would affect the supply of metal components for cable accessories as well as of cross-linked polyethylene. A full closure of borders for longer than 2 months would affect the production capacity. Furthermore, such closure would affect the distribution of finished goods, a problem which would be compounded in high-infection areas, significantly increasing transportation costs. Moreover, the closure of intra-EU borders affect the movement of workers necessary for the cables installation. Transportation costs was also affected. In contrast, as only a few raw materials suppliers are located outside the EU, a closure of borders with third countries would affect perhaps only the supply of some metal components.

EU network operators had to take a number of measures to assure the safe operation of the system and personnel safety during the COVID-19 crisis. The main impacts and measures relate to:

- **Control centres**, as social distancing and lockdown measures required strict access procedures. Belman (2020)[612] indicates additional measures were taken, such as hygiene, use of private or company-organised transport, shift changes, and sequestering of personnel. These were among the most strict measures taken by network operators[613], and is confirmed by the Commission document on energy security good practices to address pandemic risk[614];
- **Facility maintenance schedules,** as network operators and generators either postponed or changed their maintenance procedures. The ENTSO-E Summer Outlook[615] did not identify major electricity supply adequacy risks in Europe, as electricity TSOs found that postponed scheduled maintenance in supply and transmission assets did not impact adequacy in severe Summer scenarios. ENTSO-E even stated that, while uncertainty was high, COVID-19 could improve adequacy, due to an expected reduction in total summer electricity demand. In the Winter 2020/2021 Outlook, ENTSO-E notes COVID-19 increases the uncertainty but does not

[611] T&D Europe. (2020). Europe's grid technology providers highlight the essential role of the transmission and distribution sector.
[612] Belmans et al. (2020). COVID 19: The impact on the power system and lessons from the energy transition
[613] IEEE Power & Energy Society. (2020). Sharing Knowledge on Electrical Energy Industry's First Response to COVID-19.
[614] European Commission. (2020). SWD(2020) 104 final. Energy Security: Good Practices to Address Pandemic Risks.
[615] ENTSO-E. (2020). 2020 Summer Outlook - Winter Review 2019/2020. Including country comments.

identifies significant risks, even if the pandemic can 'slow maintenance works during planned and unplanned outages'[616];

- **Sourcing of parts and materials,** as global supply chain disruptions may hamper the source of personal protective equipment (PPE) and equipment and component for new projects and maintenance. While e.g. an utility in the US had difficulties sources transformers from China, in general system operators indicate they have managed to address eventual disruptions to upstream supply chains; However, sourcing of PPE was a more frequent issue for network operators. As part of major weather event preparedness, US organisations have recommendations for supply disruptions affecting the electricity sector.[617]
- **Meters reading and installation,** with network operators sometimes billing average values based on historical consumption for customers with readers lacking remote reading capabilities, or postponing installation for budget/smart meters. [618]
- **System control**, as the overall reduced demand levels led to unusual flow patterns as well as increased contribution of intermittent renewables, required TSOs to take control measures to ensure system stability, with some regions showing voltage control challenges, for example Switzerland.[619] However, in Europe network operators were able to maintain normal system operation.[620,621] There could be challenges related to reverse flows from the distribution to the transmission level in systems with high levels of distributed generation.[622]

These actions taken by the electricity network operators are confirmed by the European Commission as significant good practices to reduce energy security risks in the face of pandemics[623];

The increasing deployment of smart meters provides greater visibility on the network conditions with a high level of detail, allowing to measure system reliability in a disaggregated manner (instead of relying on usual interruption frequency and duration indices).[624]

Therefore, in general network operators were able to maintain safe system operation and personnel safety throughout the summer. However, due to the rescheduling of outages for maintenance, resource availability in the 2020/2021 winter could be reduced. [625]

[616] ENTSO-E. (2020). Winter Outlook 2020-2021 / Summer Review 2020.
[617] IEEE Power & Energy Society. (2020). Sharing Knowledge on Electrical Energy Industry's First Response to COVID-19.
[618] Eurelectric. (2020). Impact of COVID-19 on the electricity value chain.
Belmans et al. (2020). COVID 19: The impact on the power system and lessons from the energy transition.
[619] ENTSO-E. (2020). 2020 Summer Outlook - Winter Review 2019/2020. Including country comments.
[620] Belmans et al. (2020). COVID 19: The impact on the power system and lessons from the energy transition.
[621] ENTSO-E. (2020). Winter Outlook 2020-2021 / Summer Review 2020.
[622] IEEE Power & Energy Society. (2020). Sharing Knowledge on Electrical Energy Industry's First Response to COVID-19.
[623] European Commission. (2020). Energy Security: Good Practices to Address Pandemic Risks. SWD(2020) 104 final.
[624] IEEE Power & Energy Society. (2020) Sharing Knowledge on Electrical Energy Industry's First Response to COVID-19.
[625] ENTSO-E. (2020). 2020 Summer Outlook - Winter Review 2019/2020. Including country comments.

5.9. Batteries

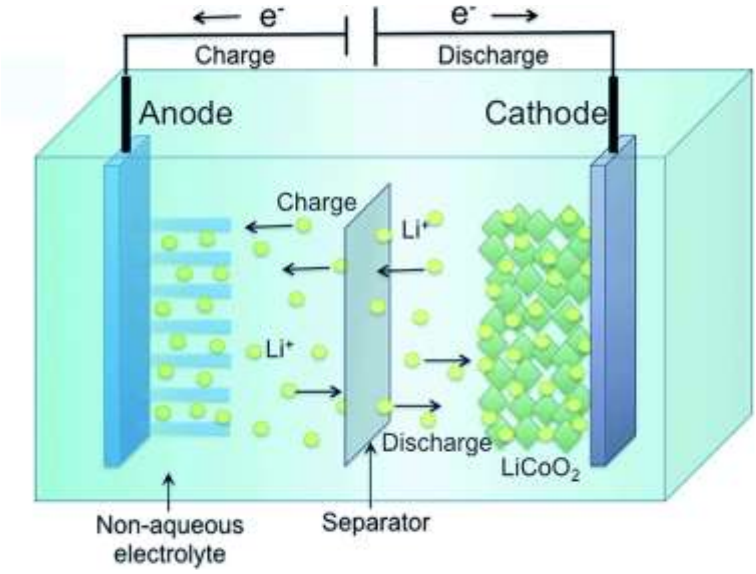
Introduction and technology description

Batteries are energy storage technologies based on the principle of electrochemistry. They can convert chemical energy into electrical energy. Batteries are based on a wide range of different chemistry processes. They can be divides into primary (single use) and secondary (rechargeable) batteries. The Batteries Directive defines three main categories of batteries: portable, automotive, and industrial.[626] However, from an application perspective, batteries can be categorized into:

- Portable batteries (primarily used in consumer devices, Lithium (Li)-based)
- Industrial batteries (predominantly lead-based)
- Starting-lighting ignition batteries (lead based, used in cars)
- Clean Vehicles batteries (mostly Li-based)
- Power grid batteries (including facilities to provide balancing, system services and ancillary services)

Given the focus of this study, the emphasis will be on batteries for the last two applications. Given the predominance of Lithium (Li)-ion batteries (LIB), the focus will be on this type of technology. LIB operate based on the movement of lithium-ions from a negative (anode) to a positive (cathode) electrode while using a non-aqueous electrolyte solution as a conductive medium. Lithium is the lightest metal and has a very high standard reduction potential (> -3.0V). These characteristics give Li a favourable energy content.

Figure 5-40 Overview of working principle behind LIB[627]



There are multiple cathode chemistries possible for lithium-ion batteries, for electric vehicles (EV) the main ones being Nickel Manganese Cobalt oxide (NMC) and Nickel Cobalt Aluminum oxide (NCA). For these, the cathode represents 15 to 25% of the costs of an EV battery pack and the anode slightly over 5%, but still other costs besides the main components represent over 50% of total costs. For stationary storage, materials represent 65 to 80% of total battery pack costs, with the rest amounting to labour, overhead, margins and other costs. But while the main components (anode, cathode, electrolyte and separator) represent most of the costs of a stationary battery pack, when considering the total system cost these represent around 30% of the battery storage system.[628]

The supply chain of batteries

The supply chain of batteries can be separated into the stages shown below.

[626] European Commission. (2006). Directive 2006/66/EC.
[627] Civilsdaily. (2019). Nobel Prize in Chemistry: for Lithium ion battery. Available at: https://www.civilsdaily.com/news/nobel-prize-in-chemistry-for-lithium-ion-battery/
[628] Tripolos, I., Tarvydas, D., Lebedeva, N., 2018. et al. (2018). Li-ion batteries for mobility and stationary storage applications. JRC Science for Policy Report.

Figure 5-41 Vulnerabilities in the batteries supply chain

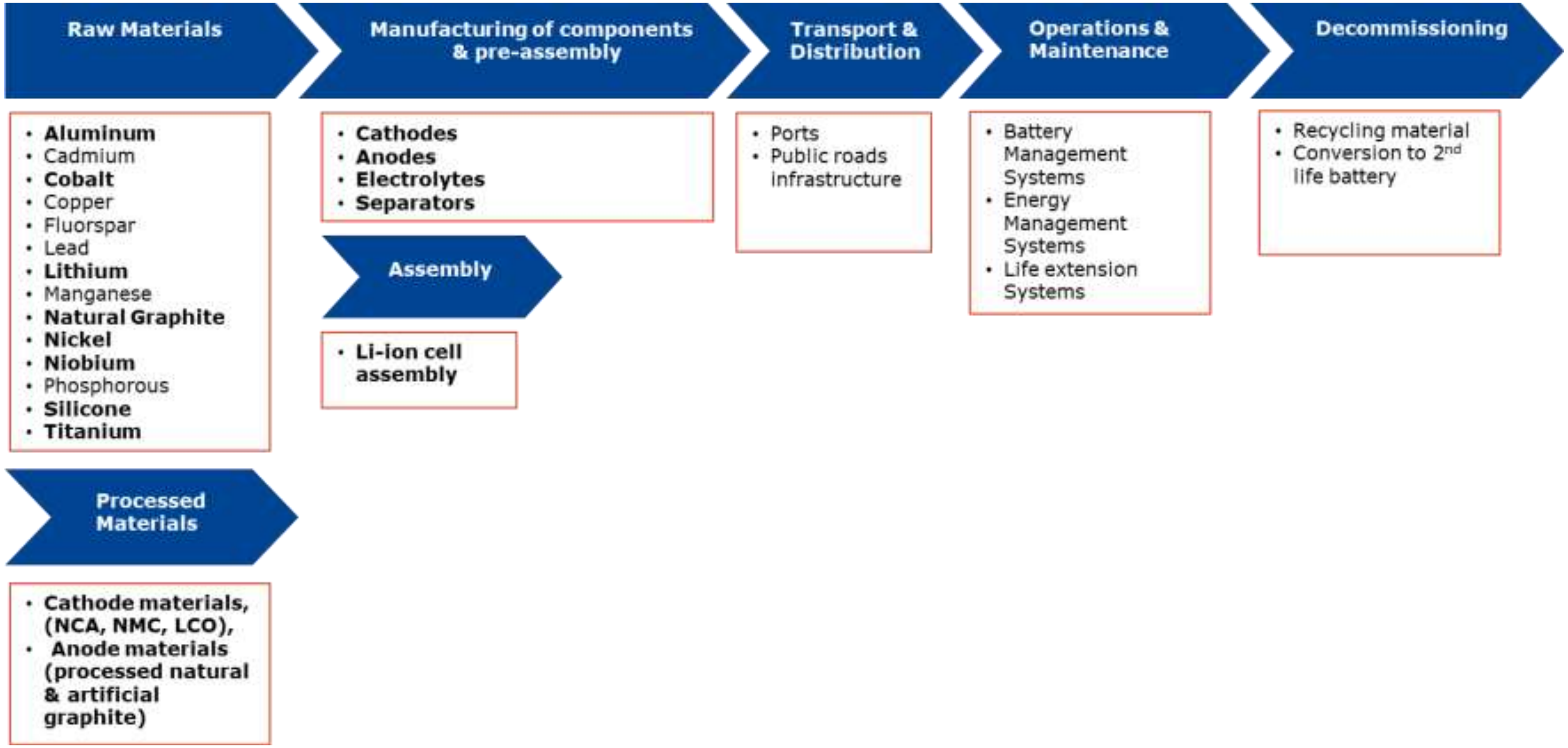
	Supply chain stage	Vulnerable element	Import dependency	Market concentration	Easy of substitutability	Price stability
			Import reliance	CR4 / Main suppliers	Qualitative analysis	Coefficient of variation
Batteries	Raw materials	Aluminim	64%	79% (AU, CN, GN, BR)	Medium by cooper	22%
		Cadmium	6%	94% (NL, DE, PL, BG)	NiCd batteries cannot be substituted in applications, where reliability and stability is of major importance.	Downward trend
		Cobalt	86%	76% (CD, CN, CA, CU)	Medium	Follow similar trends to those of Ni
		Copper	42%	58% (PL, CL, PE, ES)	Medium by aluminium	42%
		Fluorospar	66%	61% (MX, ZA, BG, ES)	Medium by plastics, stainless steel, ceramics and aluminim	Downward trend
		Lead	18%	58% (DE, IT, ES, PL)	Medium	Lost ~ 25% of its value through 2018
		Lithium	100%	96% (AU, CL, AR, CN)	Medium	Downword trend since mid-2018
		Manganese	89%	62% (NO, ES, ZA, FR)	Low	Lost ~ 25% of its value through 2018
		Natural Graphite	98%	89% (CN, BR, NK, IN)	Low	NA
		Nickel	59%	59% (CN, RU, JP, CA)	Medium	50%
		Niobium	100%	100% (BR, CA, Others)	Medium	Downward trend
		Phosphrous (elemental)	100%	98% (KZ, VN, CN)	Low	NA
		Silicone	68%	68% (NO, FR, CN, BR)	Low for metallurgical silicion	NA
		Titanium	100%	57% (CA, AU, ZA, CN)	Medium	High volatility
	Processed materials	Cathode materials (NCA, NMC, LCO, anode materials)	93%	NA	NA	NA
	Components / Equipment / Assembly	Cathode, anode, electrolyte separator	92%	NA	NA	NA
		Li-ion cells	100%	NA	NA	NA

Notes: CR4 – concentration ratio of 4 largest suppliers. Extra-EU – CR only for third country suppliers.
Sources: Eurostat PRODCOM/COMEXT; JRC. (2020). Study on the EU's list of Critical Raw Materials; other sources listed in section.

The selection of the highly vulnerable elements is based on the assessment of the following criteria, but also on the literature review and stakeholder consultation. Some elements may appear to be highly vulnerable according to the assessment of these criteria, but for several other reasons (e.g. limited amount needed), both the literature and the stakeholders do not lead to the conclusion they should be considered as such. Therefore, these criteria should only be considered as a preliminary assessment of the vulnerability of the elements, which is refined with other information sources.

Vulnerable elements are highlighted in bold in the following Figure 5-42 illustrating the batteries value chain.

Figure 5-42 The batteries supply chain



The main vulnerabilities, highlighted in bold in Figure 5-42, are developed below:

Raw and processed materials[629]

EU produces only 1% of all LIB raw materials overall.[630] In Figure 5-42, the first supply chain block lists the most relevant raw materials required for the manufacturing of different types of batteries. **Cobalt** is an important raw material used in the production of the cathode of LIB. It is also used in the production of other batteries such as nickel-cadmium or nickel-metal hydride batteries. In 2017, 60.85% of cobalt worldwide came from the Democratic Republic of Congo. China was the second largest producer with 6.64% of the share followed by Canada (4.8%) and Cuba (4%). Refined cobalt production comes predominantly from China, Finland, Canada and Belgium. An analysis of cobalt availability for electric mobility points to potential deficit in cobalt supply despite efforts to substitute the material.[631] Cobalt is expected to see a spike in demand, growing 500% by 2030 and 15 times by 2050.

In 2017, **lithium** was mostly produced in Australia (49.3%), Chile (30.3%), Argentina (11.52%) and China (4.57%). The supply of lithium is not expected to be a major issue for the battery supply chain in the short or medium term given that there is sufficient capacity available in the near future. Nevertheless, an increase from current prices could be necessary to support the development of new production capacity.[632] Demand for lithium is expected to increase 16-fold by the end of the decade and be 60 times larger by 2050. However, this reliance is forecasted to diminished significantly based on European mining projects being developed. For example, in April 2020 a mining project in the Czech Republic was granted 29.1 million EUR in funding and is expected to become the first EU producer of battery grade lithium. In Serbia, the Rio Tinto company will invest 200 million USA in a lithium-borate project. It is estimated that 80% of lithium needed for batteries and storage could come from European sources by 2025.[633]

Natural graphite is another important raw material in the batteries supply chain. China supplies about 71% of the global production followed by Brazil, North Korea and India. Manufacturing of anode materials in batteries makes up for around 10% of the global natural graphite demand. Natural graphite can be substitutes by a synthetic version.

About two-thirds of **nickel** ore is produces in the following counties: Indonesia, the Philippines, Australia, Russia and Canada. China produces around 30% of the refined nickel. It is important to note that not all nickel is suitable for the production of LIB. Although the supply of nickel is more diversified compared to cobalt and lithium, Europe still relies for imports of this material with a share of ~ 56%.

Silicon, **titanium**, and **niobium** are expected to play an important role in the future production of anodes. Currently, research is focused on looking at these materials to improve the energy density, durability and safety in future types of LIB.

Components manufacturing and integration[634]

As seen from Figure 5-43, Asia, and more specifically China, dominates the entire LIB supply chain. For example, China provides 48% of the total processed materials and components and together with Japan and South Korea make up 86% of all processed materials and components for LIB. In addition to the Asian players mentioned, the USA has considerable manufacturing capabilities of Li-ion cells (13% global share). Europe currently lacks the capacity to process materials required to produce LIB, such as anode materials and NCA cathode materials. Europe is fully dependent on the supply anode materials and NCA cathode material. It delivers about 18% of Nickel Manganese Cobalt

[629] Section largely based on the EC's (2020) Raw Material Information System (RIMS) – Raw Materials in the Battery Value Chain. Available at: https://rmis.jrc.ec.europa.eu/apps/bvc/#/

[630] JRC. (2020). Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study. Available at: https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

[631] Alves Dias P. Et. al. (JRC). (2018). Cobalt: demand-supply balances in the transition to electric mobility. Available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC112285/jrc112285_cobalt.pdf

[632] Roskill. (2019). Lithium: current prices provide limited incentive for new supply. Available at: https://roskill.com/news/lithium-current-prices-provide-limited-incentive-for-new-supply/

[633] Euractiv. (November 9, 2020). Raw materials: the missing link in Europe's drive for batteries. Available at: https://www.euractiv.com/section/energy-environment/news/raw-materials-the-missing-link-in-europes-drive-for-batteries/

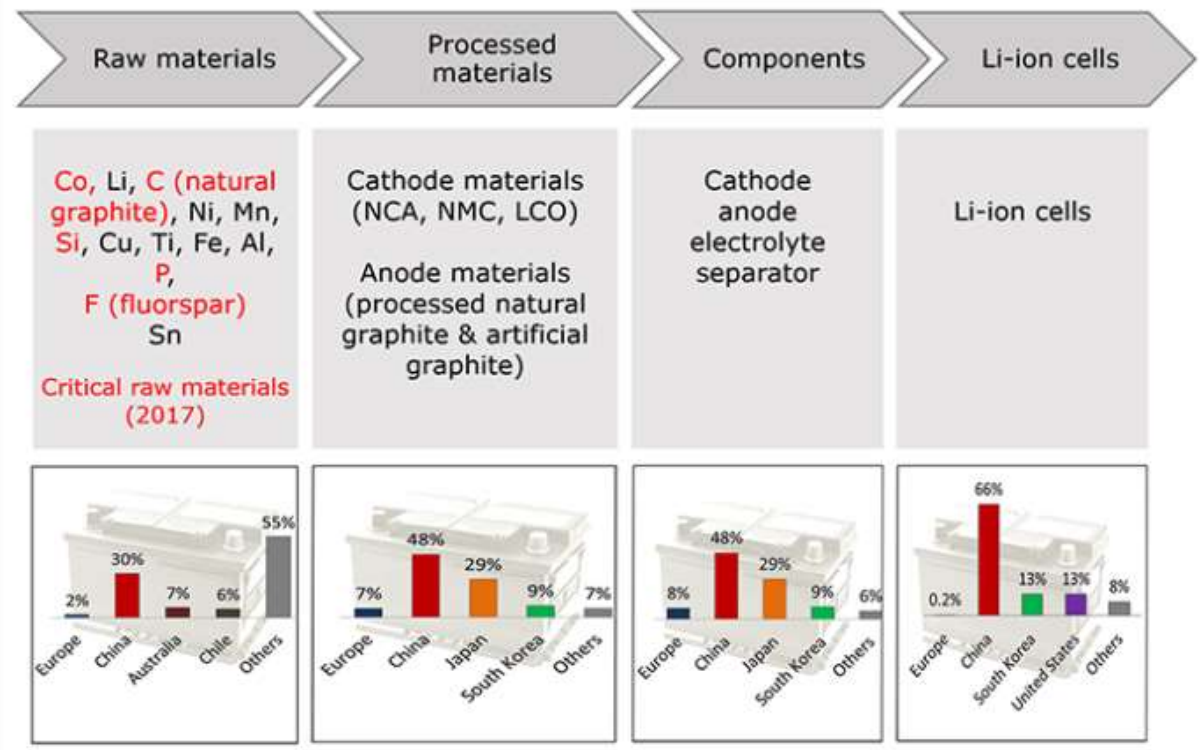
[634] Section largely based on the European Commission. (2020). Raw Material Information System (RIMS) – Raw Materials in the Battery Value Chain. Available at: https://rmis.jrc.ec.europa.eu/apps/bvc/#/

oxide and 15% Lithium Cobalt oxide processed materials. Critically, these volumes are not enough to satisfy the European demand for LIB.[635]

Li-ion cell production in Europe is well below the 1% (~ 0.2%) of the global share and thus can be considered negligible. This exposes the industry to supply uncertainties and potential high-costs.[636]

For the purpose of producing Electric Vehicle (EV) battery packs, the European capacity is currently of 3GWh, this capacity is expected to grow to about 40 GWh by 2021-2023.[637]

Figure 5-43 LIB - key players along the supply chain[638]



Europe is catching up with Asia in terms of investments in the battery sector. In fact, Europe invested significantly more than China in the sector in 2019 (60 billion EUR vs 17 billion EUR). This year, Europe has invested 25 billion EUR, corresponding to double the investments by China.[639] In July of 2020, the European Investment Bank issues a 30 million EUR loan for the construction of the first domestic battery gigafactory. The factory will be constructed in Sweden by Northvolt and plans for an initial annual production capacity of 16 GWh. This capacity could eventually be ramped up to 40 GWH.[640]

[635] JRC. (2020). Critical Raw Materials for Strategic Technologies and Sectors in the EU: A Foresight Study. Available at: https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf
[636] Ibid.
[637] Triropoulos, I. Et al.(JRC). (2018). Li-ion batteries for mobility and stationary storage applications. Available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC113360/kjna29440enn.pdf
[638] Huisman, J., Ciuta, T., Mathieux, F., Bobba, S., Georgitzikis, K. and Pennington, D. (2020). RMIS – Raw materials in the battery value chain, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-13854-9, doi:10.2760/239710, JRC118410, based on Blagoeva et al. 2019.
[639] Euractiv. (November 9, 2020). Raw materials: the missing link in Europe's drive for batteries. Available at: https://www.euractiv.com/section/energy-environment/news/raw-materials-the-missing-link-in-europes-drive-for-batteries/
[640640] Euractiv. (August 28, 2020). Europe is 'closing the gap' on battery manufacturing, Northvolt says. Available at: https://www.euractiv.com/section/energy-environment/news/europe-is-closing-the-gap-on-battery-manufacturing-northvolt-says/
Euractiv. (July 30, 2020) EU invests EUR350m in first domestic battery Gigafactory. Available at: https://www.euractiv.com/section/batteries/news/eu-invests-e350m-in-first-domestic-battery-gigafactory/

Evidence of short-term vulnerability to the COVID-19 pandemic

In spite of the coronavirus outbreak, Commission Vice-President Maroš Šefčovič, announced in May, 2020 that the plans of the EU Battery Alliance were proceeding as planned.[641] The reference includes the Important Project of Common European Interest (IPCEI) launched in France in January of this year, and a second IPCEI currently being prepared by Germany.[642]

[641] Euractiv. (May 20, 2020). EU's battery mega-projects charge on despite virus. Available at: https://www.euractiv.com/section/batteries/news/eus-battery-mega-projects-charge-on-despite-virus/

[642] European Commission. (2020). Statement by Vice-President Maroš Šefčovič following the meeting with high-level industrial actors under the European Battery Alliance. Available at: https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_20_914

5.10. Smart buildings and building automation

Introduction and technology description

This analysis focuses on the supply chain for smart buildings and building automation and control technology. Building automation and control systems comprise "*all products and engineering services for automatic controls (including interlocks), monitoring, optimization, for operation, human intervention and management to achieve energy–efficient, economical and safe operation of building services. Controls herein do also refer to processing of data and information*".

It deals particularly with home energy management systems (HEMS) and building energy management systems (BEMS), and the associated equipment and appliances necessary for such management. HEMS and BEMS are collectively referred here as energy management systems (EMS). Building energy management systems (and by extension home energy management systems) can be defined as "*IT-based solutions that extends the capabilities of sensing, control, and automation hardware to direct automated and/or manual improvements to system operations utilizing the data from multiple data streams*".[643] The literature usually does not provide clear definitions differentiating BEMS and HEMS. While HEMS may be employed in single family homes as well as multi-family housing units, BEMS may apply to non-residential buildings as well as multi-family housing units. There is hence some overlap between HEMS and BEMS concerning residential buildings, where the two systems could even be combined (with BEMS controlling building functions – e.g. public area lighting, HVAC - and HEMS controlling individual family housing units).

Hence, building automation and control systems comprise the IT and OT (operational technology) software and hardware as well as services to extend the capabilities of and is intrinsically linked to the digitalisation of building and home equipment and appliances.[644]

BNEF estimates that global investments in home energy management systems will total 11 billion USD in 2025 (Figure 5-44)[645], while Navigant estimated that the global market for building energy management systems would reach almost 13 billion USD by the same year (Figure 5-45)[646].

[643] Navigant. (2016). Research Leaderboard Report: Building Energy Management Systems. Available at: https://f.nordiskemedier.dk/2gq3k2u9zf56js6a.pdf
[644] European Commission. (2020). SWD(2020) 953. Clean Energy Transition – Technologies and Innovations.
[645] BloombergNEF. (2017). Market for Digitalization in Energy Sector to Grow to $64BN by 2025. Available at: https://about.bnef.com/blog/market-digitalization-energy-sector-grow-64bn-2025/#:~:text=Market%20for%20Digitalization%20in%20Energy%20Sector%20to%20Grow%20to%20%2464BN%20by%202025,-November%207%2C%202017&text=Digital%20technologies%20for%20fossil%20fuel,renewables%20and%20the%20connected%20home.
[646] Navigant. (2016). Research Leaderboard Report: Building Energy Management Systems. Available at: https://f.nordiskemedier.dk/2gq3k2u9zf56js6a.pdf

Figure 5-44 Market size for digital technologies in the energy sector[647]

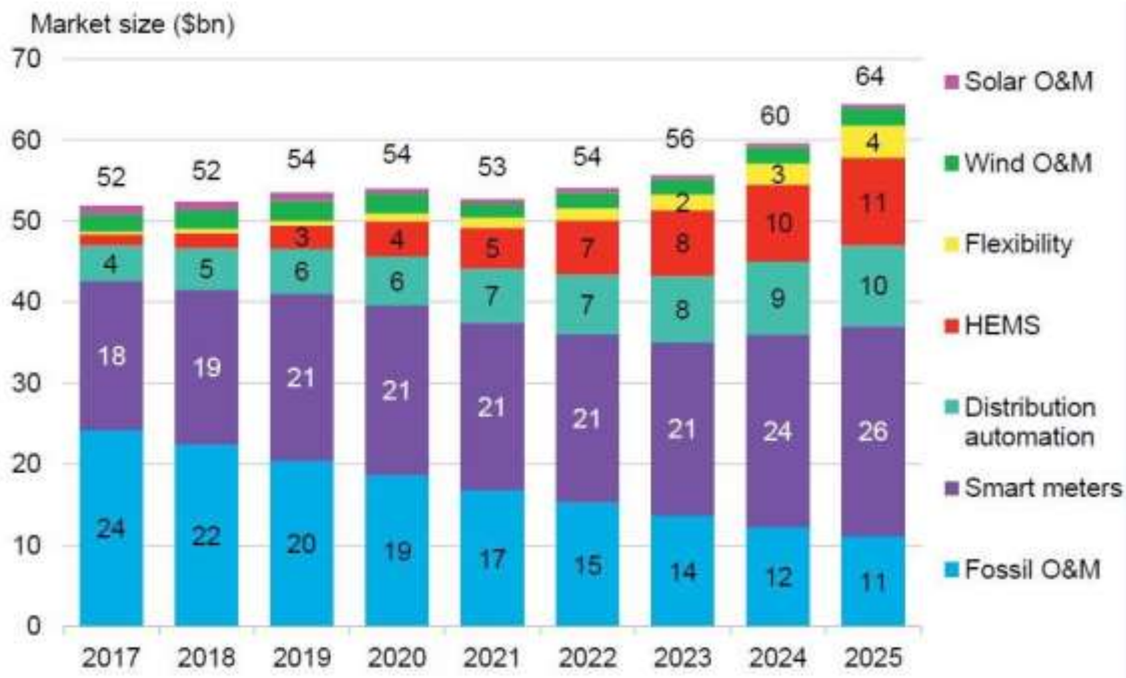


Figure 5-45 Global BEMS market by offering type[648]

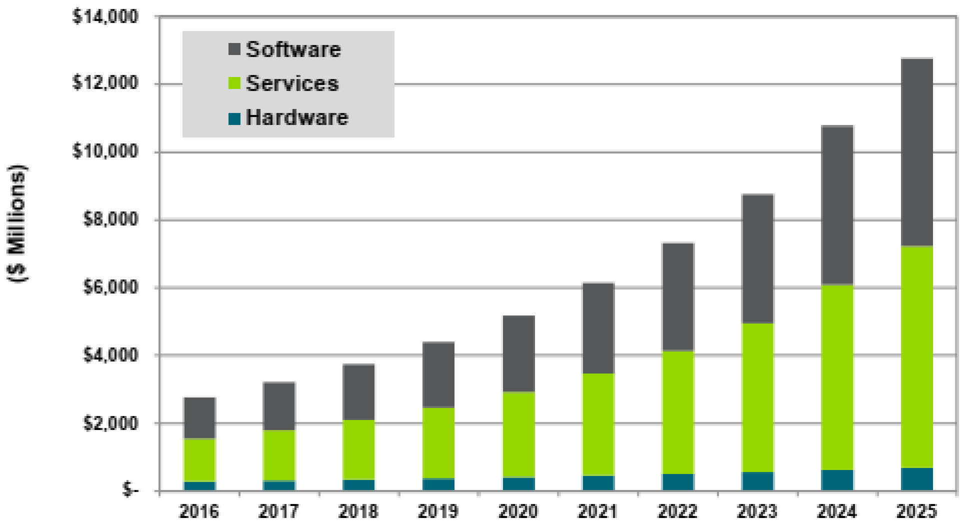
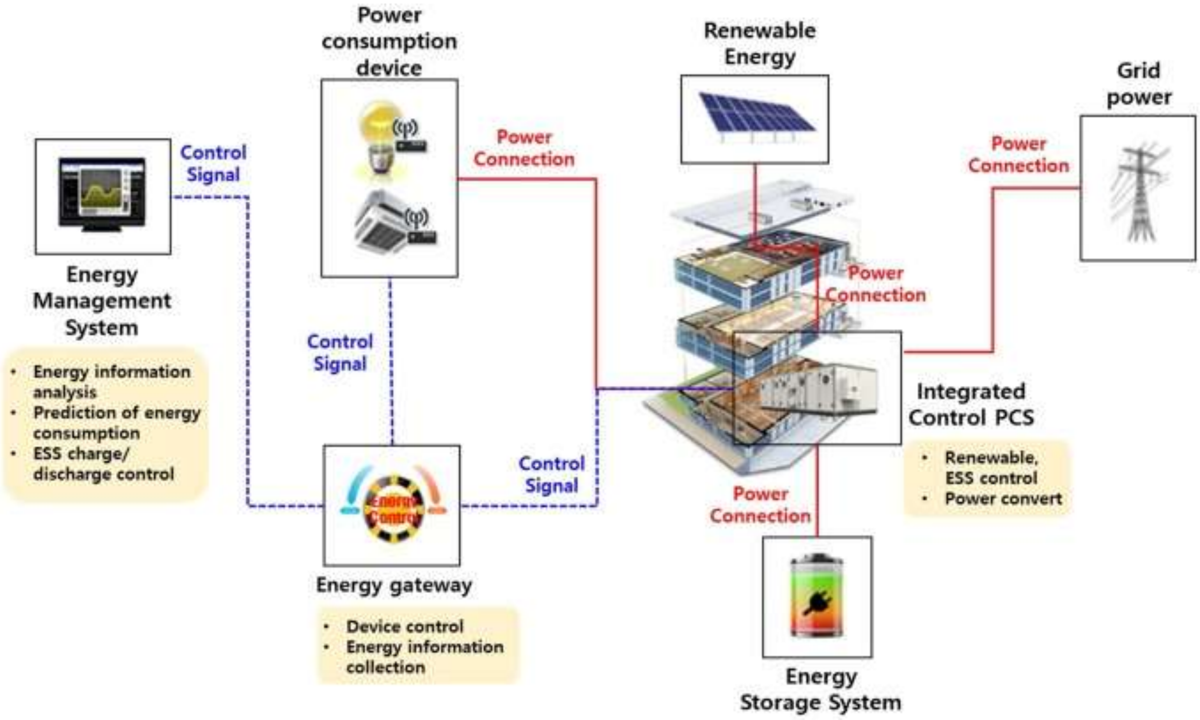


Figure 5-45 illustrates the connection of a BEMS with the other building equipment and appliances related to lighting, heating, ventilation and air conditioning (HVAC), decentralised renewable energy supply and energy storage.[649]

[647] BNEF (2017) Market for Digitalization in Energy Sector to Grow to $64BN by 2025
[648] Navigant. (2016). Research Leaderboard Report: Building Energy Management Systems.
[649] Yoon et al. (2020). Multiple power-based building energy management system for efficient management of building energy. Sustainable Cities and Society 42.

Figure 5-46 Building energy management system and interaction with the grid and other building equipment and appliances[650]



Given that the main EMS assemblies to be installed on site consist especially of the software and of the servers for data processing, metering and control of appliances and equipment, the raw and processed materials relevant to the technology are the same as those for digital technologies in general. Often the EMS and data storage will be hosted remotely – in this case data processing capacity can be contracted from third-parties as needed, and no data server needs to be installed in the building or home. Likewise, EMS platforms can be accessible online through computers and remove devices, without the need of dedicated user interfaces. Energy management system vendors can thus still have a significant role in the operation of the systems by hosting their platforms remotely.

The supply chain of smart buildings and building automation

An analysis of supply chain elements (summarised in Figure 5-47) was conducted to identify potentially vulnerable elements. The selection of the highly vulnerable elements is based on the assessment presented in the figure, but also on the literature review and stakeholder consultation. Some elements may appear to be highly vulnerable according to the assessment of these criteria, but for several other reasons (e.g. limited amount needed), both the literature and the stakeholders do not lead to the conclusion they should be considered as such.
Therefore, these criteria (Figure 5-47) should only be considered as a preliminary assessment of the vulnerability of the elements, which is refined with other information sources.

Considering this, the following elements are identified as vulnerable: several raw materials (B, Co, Ga, Ge, In, Li, Mg, graphite, platinum-group metals, rare earth elements, Si, W), home energy management systems and home/building energy management systems and decentralised devices (due to cyber security). In addition, vulnerable elements from the digital technologies supply chain are widely used in smart buildings and building automation technologies (servers and data storage equipment, printed circuit boards and other electronics). These are analysed in detail in the digital technologies supply chain. Vulnerable elements are highlighted in bold in Figure 5-48, which presents an overview of the smart buildings technology supply chain.

[650] Ibid.

Figure 5-47 Vulnerability in the smart buildings technology supply chain

	Supply chain stage	Vulnerable element	Import dependency	Know-how/specialisation	Market concentration	Easy of substitutability	Price stability
			Import reliance	Patents share / other	CR4 / Main suppliers	Qualitative analysis	Coefficient of variation
Smart Buildings	Raw/processed materials	Boron	100%	NA	99% (TR, AR, NO, BO)	Low	NA
		Cobalt	86%	NA	92% (CD, FI, GF, RU)	Medium	52%
		Graphite	98%	NA	67% (CR3) (CN, BR, NO)	Low	NA
		Arsenic	32%	NA	100% (BE, CN, JP, HK)	Medium	NA
		Gallium	31%	NA	94% (DE, UK, CN, US)	Low	NA
		Germanium	31%	NA	89% (FI, CN, UK, RU)	Medium	~14% (4 years)
		Silicon metal	63%	NA	68% (NO, FR, CN, BR)	Low	~10-15% (4 years)
		Lithium	100%	NA	93% (CL, US, RU, CN)	Medium	NA
		PGMs	98%	NA	96% (platinum) (ZA, RU, ZW, CA)	Medium	34% (Platinum)
		Indium	0%	NA	72% (FR, BE, UK, DE)	Low	NA
		Magnesium	100%	NA	99% (CN, UK, IL, RU)	Medium	~10% (4 years)
		Tunsten	>70%	NA	88% (CN, VN, US, RU)	Low	~20% (4 years)
		Nickel	59%	NA	59% (CN, RU, JP, CA)	Medium	50%
		Chromium	66%	NA	86% (ZA, TR, KZ, IN)	Low	Overall increase from 2012 to 2017
		Copper	44%	NA	58% (PL, CL, PE, ES)	Medium, by aluminium	42%
		Gold	NA	NA	37% (CN, AU, RU, US)	Varies per application	48%
		Silver	40%	NA	54% (MX, PE, CN, AU)	Varies per application	54%
		Manganese	89%	NA	62% (NO, ES, ZA, FR)	Low	Lost ~25% of its value through 2018
		Light rare earth elements	100%	NA	100% (neodymiun) (CN, UK)	Low	NA
		Heavy rare earth elements	100%	NA	100% (dysprosium) (CN, UK)	Low	NA
	Components / Equipment / Assembly	Electronics	See digital technologies supply chain fiche				
		BAC products and systems	EU companies are significant players		Medium concentration	NA	NA
		BEM software	EU companies are significant players		Medium concentration	NA	NA
		HEM software	Leading US position		Medium concentration	NA	NA
		Smart lighting	NA	Leading EU position with 35% of global market.	NA	NA	NA

Notes: CR4 – concentration ratio of 4 largest suppliers.
Sources: Eurostat PRODCOM/COMEXT; JRC. (2020). Study on the EU's list of Critical Raw Materials; VITO et al. (2020). Ecodesign preparatory study for Building Automation and Control Systems (BACS) implementing the Ecodesign Working Plan 2016 - 2019 Draft final - Task 2 report: Markets; European Patent Office. (2020). Patent statistics; FastMarkets for price data of certain raw materials; other sources listed in section.

Figure 5-48 The supply chain of smart buildings and building automation

Raw Materials

- **Boron**
- **Cobalt**
- **Gallium**
- **Germanium**
- **Silicon**
- **Lithium**
- **PGMs**
- **Graphite**
- **Indium**
- **Magnesium**
- **Rare earth elements**
- **Tungsten**
- Arsenic
- Nickel
- Chromium
- Copper
- Gold
- Silver
- Manganese

Manufacturing of components & pre-assembly

Components & sub-components

- **Printed circuit boards**
- **Other electronics**
- Routers/switches
- GPRS modules
- Cables
- Human-machine interfaces
- Controls for
  - Energy storage
  - HVAC equipment
  - Lighting
  - Energy storage
  - On-site energy generation
- Sensors
- Electronic radiator valves
- Piping

Assemblies

- Software
  - **HEMS**
  - BEMS
- **Servers and data storage**
- Metering / control servers

Transport & Distribution

- Roads
- Shipping
- Rail

Construction & Installation

- Civil works
- Electrical works
- Systems commissioning

Operations & Maintenance

- **Systems O&M**
- **Third-party services** (VPN, cloud storage, etc)
- Trained personnel
- Communications infrastructure

*Note: vulnerable elements found highlighted in **bold**; GPRS: General Packet Radio Service.*
Sources: Refrigeration Industry (2019) HVAC&R Market in the EMEA Region in 2018; other sources listed in the section.

The analysis of elements of the smart buildings technology supply chain, in particular vulnerable elements highlighted in bold in Figure 5-48, is detailed below.

Raw and processed materials

A number of raw and processed materials are generally employed in the manufacturing of digital equipment for home and building energy management systems. 12 of these (groups of) raw or processed materials are critical, mostly related to the manufacturing of digital technology components: boron, cobalt, gallium, germanium, graphite, indium, lithium, magnesium, PGMs, rare earth elements, silicon and tungsten. Rare earth elements have the highest supply risk, followed by magnesium, germanium and borates. The main suppliers for these materials are China (41%) and African countries (30%). On one hand that the digital technologies demand growths at an accelerated pace and that the sector innovation cycles are markedly shorter than in other technology sectors, but that on the other hand substitution dynamics mean that demand for certain critical raw elements may stagnate or even decrease, depending on the importance of the difference drivers.[651]

Components manufacturing and integration

The market for energy management equipment and related software is in general highly concentrated, with European players having a strong position. According to the preparatory study on ecodesign requirements for Building Automation and Control Systems (BACS),[652] building automation and control equipment (BAC) accounts for 42% and installation for 35% of the final BACS market value in the EU, with wholesale responding for other 10%, retail for 11%, and maintenance for the final 3% (combining residential and non-residential BACS).

The study lists as major BACS suppliers for the EU market Siemens Building Technologies (DE), Honeywell Technologies (US), Johnson Controls (US), Schneider Electric Buildings (FR), and Kieback & Peter (DE). The first four companies would account for 54% of the non-residential European market. The study furthermore provides a list of over 25 companies member of the eu.bac industry association, which account for 85% of the European market. Many of those are based in Germany or Switzerland (this includes European branches of Honeywell and Johnson Controls). ABB (CH), GE and Eaton (US) also provide BEMS.[653] For building energy management software specifically, the EU is a also leader. Others comprise EcoEnergy Insights (US), Acuity Brands (US) and ThoughtWire (CA).[654]

According to Delta-EE, there was a cumulative total of around 300 000 home energy management (HEM) installations in Europe in 2019. [655] The US is a leader in home energy management software, with only Schneider Electric (FR) being a main supplier based in Europe. Siemens does offer HEM solutions, but is not listed as a leading player in HEM software by the Clean Energy Transition – Technologies and Innovations report. Delta-E does list over 50 companies with some level of involvement with the HEM market across Europe in 2020.[656] There is, therefore, a large number of new entrants in the market – also globally. Lead US-based HEM software vendors include Bidgely, Itron, Oracle and Uplight. The EU HEM software market is much smaller than the BEM software one, amounting to under 250 million € in 2020, against over € 2 billion for the latter. [657]

With the increase of internet of things devices, virtual AI assistants and electric vehicles, a large number of new players are entering the market. Companies in the tech (Google, Apple, Facebook and Amazon), telecom (T-Mobile, Verizon and BT) as well as automotive (Tesla, Toyota, Mercedes) and energy retail (Drift, current) sectors are active in energy platform systems.[658]

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[651] European Commission. (2020). Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study. Available at: https://ec.europa.eu/docsroom/documents/42881/attachments/1/translations/en/renditions/native

[652] VITO et al. (2020). Ecodesign preparatory study for Building Automation and Control Systems (BACS) implementing the Ecodesign Working Plan 2016 - 2019 Draft final - Task 2 report: Markets.

[653] E-LAND. (2019). D7.1 Market and stakeholder analysis. Available at: https://elandh2020.eu/wp-content/uploads/2020/09/D7.1-Market-and-stakeholder-analysis.pdf

[654] Guidehouse. (2020). Insights Leaderboard: Intelligent Building Software.

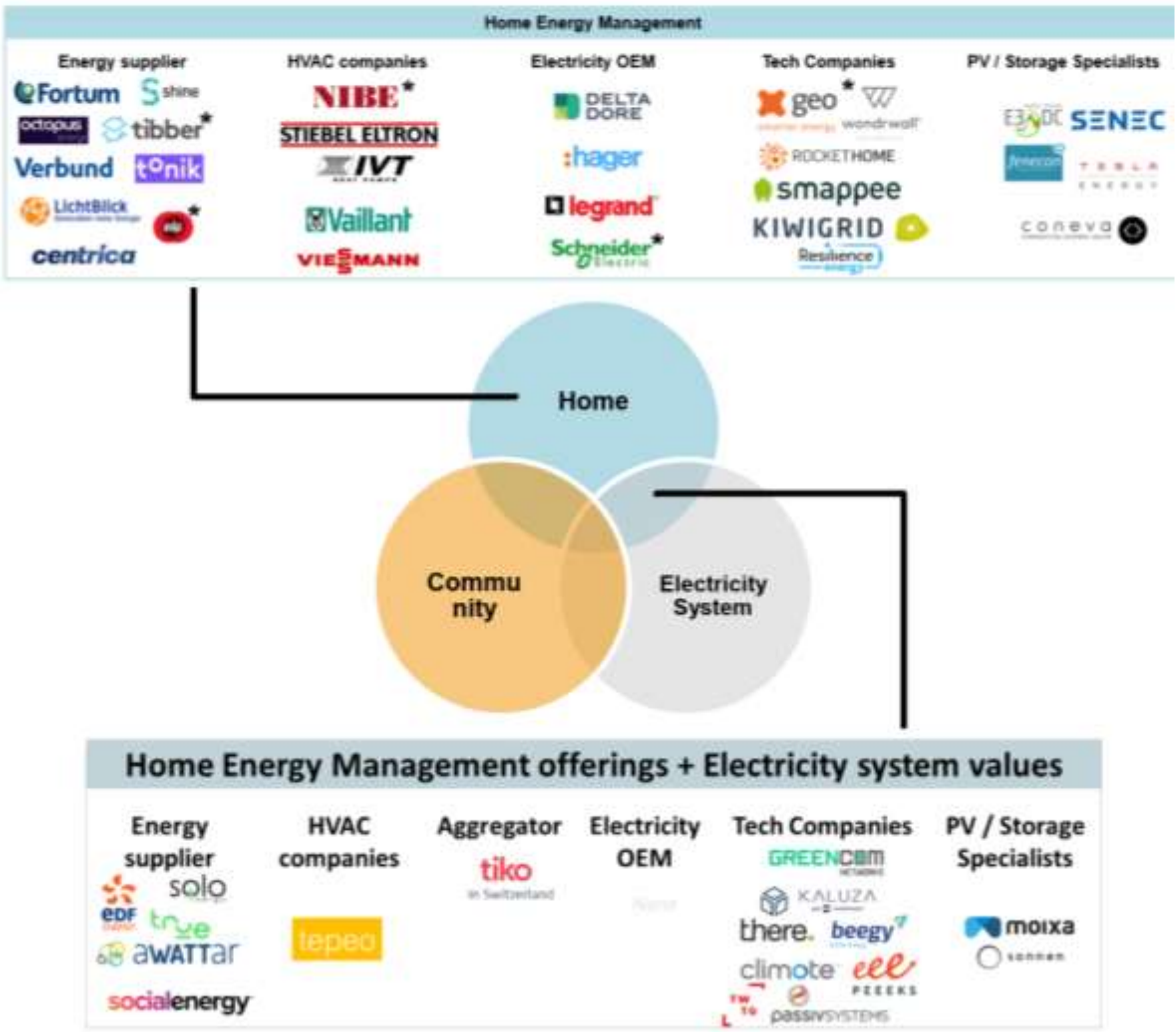
[655] Delta-EE. (2020). Whitepaper: Accelerating Accelerating the energy transition with Home Energy Management. Available at: https://www.delta-ee.com/downloads/2458-delta-ee-whitepaper-accelerating-the-energy-transition-with-home-energy-management.html

[656] Ibid.

[657] European Commission. (2020). SWD(2020) 953. Clean Energy Transition – Technologies and Innovations.

[658] Guidehouse. (2018). Energy Cloud 4.0 - Capturing Business Value Through Disruptive Energy Platforms.

Figure 5-49 Delta-EE's overview of companies active with HEMS in Europe[659]



Lighting products are important given that leading companies in the field are increasingly involved in the design and manufacture of lighting control systems. Leading EU companies include Signify/Philips (NL), Osram (DE), Cooper (IE), Zumtobel Group (AT), all of whom offer lighting management systems. Non-EU companies include GE (US), Cree (US), Virtual Extension (IL), Dialight (UK), Samsung (KR) and Sharp (JP). In 2017 two EU LED manufacturers were among the leading 10 manufacturers worldwide: Lumileds (owned by Philips, NL) and Osram (DE).[660] Cree (US), Phillips (NL), Sony (JP) and Osram (DE), with over 5% of the solid-stated lighting filled with the European Patent Office since 2010. Bibliometric data indicates that lead countries comprise China, the United States, Germany, Japan and India. [661] Major manufacturers of intelligent cooling equipment comprise Carrier (US), Daikin (JP) and Lennox International (US).[662] China is also a major manufacturer of air conditioning equipment and parts.[663]

Operation and maintenance
According to Brooks et al. (2017), "due to their physical location across all parts of a facility and connectivity with open protocols, [building energy management systems] are prone to technical and physical attacks at all architectural levels; however, the Automation level is considered the most

[659] Delta-EE. (2020). Whitepaper: Accelerating Accelerating the energy transition with Home Energy Management. Available at: https://www.delta-ee.com/downloads/2458-delta-ee-whitepaper-accelerating-the-energy-transition-with-home-energy-management.html
[660] European Commission. (2020). SWD(2020) 953. Clean Energy Transition – Technologies and Innovations.
[661] Ibid.
[662] Navigant. (2016). Advanced Energy Now 2016 Market Report. Available at: https://www.ourenergypolicy.org/wp-content/uploads/2016/03/AEN-2016-Market-Report.pdf
[663] Nicholson, S., and Booten, C. (2019). Mapping the Supply Chain for Room Air Conditioning Compressors. Available at: https://doi.org/10.2172/1524770

vulnerable."[664] The automation level is the one which controls the primary devices, through interconnected controllers. The study rates the following vulnerabilities which are relevant for the supply chain of BEMS:

- **High: Use of open source and free network programs and code**, meaning common used BEMS programs are open (for example for control through the BACnet protocol), increasing the risk that they are used to gain control of BEMS equipment;
- **Medium: Embedded functionality,** i.e. a functionality that is built-in the equipment but not activated (such as WiFi or TCP/IP connectivity), which can be activated (possibly remotely) and be used to gain access to the device.

In addition, backdoor or hidden functions allowing to gain control to the automation level could be inserted in BEMS components by malicious actors in the supply chain. This issue is further described in the digital technologies supply chain analysis.

Evidence of short-term vulnerability to the COVID-19 pandemic

COVID-19 impacted the supply chain of electronic manufacturers, especially for printed circuit boards (PCBs). Further information is provided on the fiche on the vulnerabilities of digital technologies.

[664] Brooks et al. (2017). Building automation & control systems – an investigation into vulnerabilities, current practice & security management best practice. Available at: https://www.securityindustry.org/wp-content/uploads/2018/08/BACS-Report_Final-Intelligent-Building-Management-Systems.pdf

5.11. Heat pumps

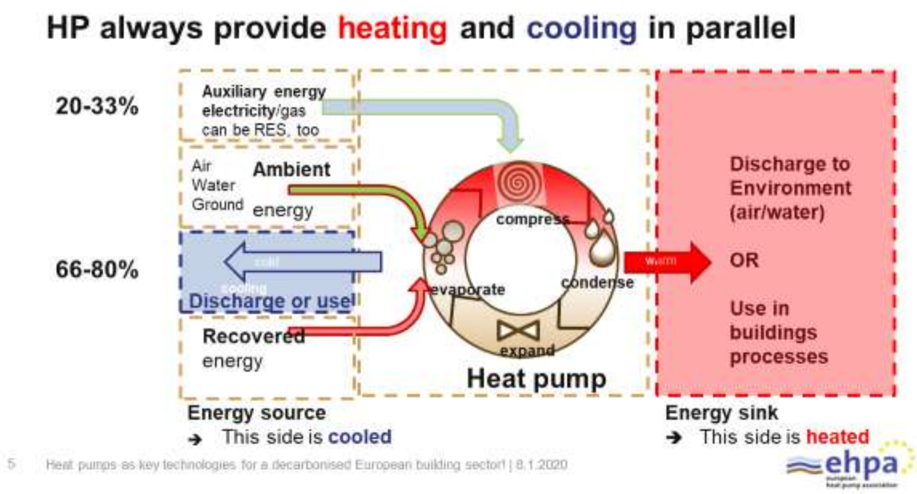
Introduction and technology description

Heat pumps transform thermal renewable energy available at low temperatures from natural surroundings to heat at higher temperatures. The heat pump (reverse) cycle can be also used to provide cooling. Heat pumps use aerothermal, hydrothermal and geothermal energy. These sources might be renewable in origin or waste energy from industrial processes and exhaust air from buildings. Energy from these sources is - with certain exceptions due to local conditions (geology, soil) and climate - available everywhere in Europe all the time. Heat pumps can be highly efficient, although their overall primary energy efficiency depends on the efficiency of the electricity production (or other thermal energy source) they use.

Heat pumps can be categorised according to the medium from which they extract renewable energy (air, water or ground), the heat transfer fluid they use (air or water) and their purpose (cooling, space heating, and water heating).

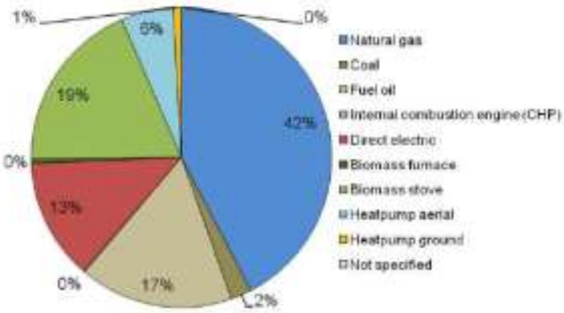
Heat pumps can be driven by mechanical energy, produced by an electric motor (electric compression heat pumps) or a combustion engine (gas/motor driven heat pumps), or by thermal energy using the principle of sorption.

Figure 5-50 Schematic overview of a heat pump producing heat and cold[665]



Heat pump technologies do not currently represent the most widespread systems to produce heat (see Figure 5-51). Nonetheless, heat pumps have so far disseminated in several EU countries such as Sweden and other Baltic and Scandinavian countries, Italy, France and Spain.

Figure 5-51 Installed heating capacity in buildings in EU-28 (Fleiter, Steinbach & Ragwitz, 2016)

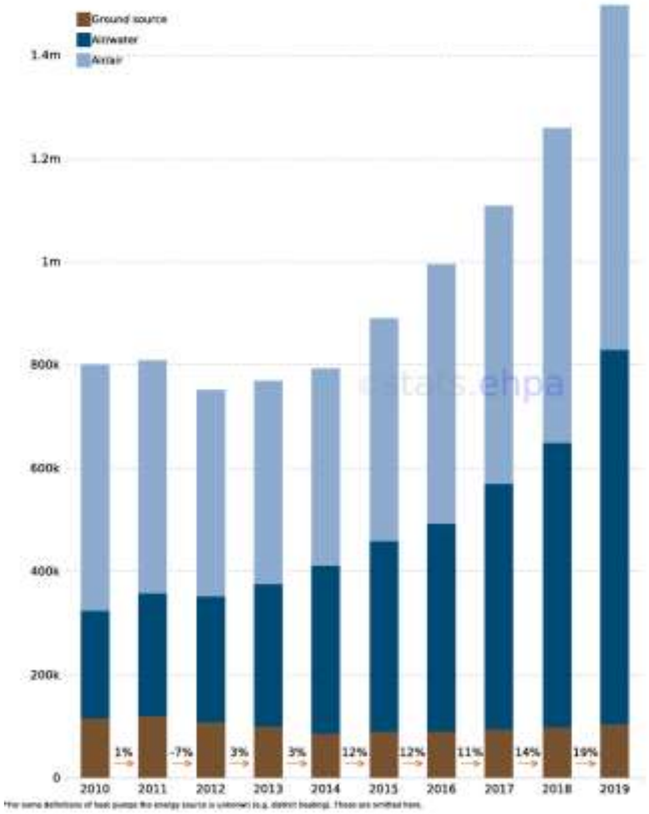


In the 1.5TECH scenario of the LTS, in the residential sector electricity share in heating grows from 14% in 2030 (5% in 2015) to 34% by 2050. The trend is stronger in services buildings, as electricity share for space heating grows from 29% (13% in 2015) in 2030 to reach 51% in 2050.
In addition to space heating, heat pumps are more and more developing industrial applications, increasing the level of temperature, although Coefficients of Performance (COP) decrease with the

[665] *Source from European Heat Pump Association*

temperature. Heat pumps cover a large spectrum of capacities from a few kW to several MW, to be used in applications ranging from households to industrial applications and district heating systems. As illustrated by Figure 5-52, the yearly market demand and the related growth in unit sales in Europe is growing rapidly (end 2018, total installed HP in Europe was about 11.8 million units).

Figure 5-52 HP market growth in Europe (annual sales in # units, 2009-2018)[666]



The supply chain of heat pumps

The Heat Pump value chain can be separated into the stages shown in Figure 5-53. No specific research has been conducted to identify critical elements in the heat pump supply chain (raw materials, compounds block).

The selection of the vulnerable elements is based on the assessment of the following criteria, but also on the literature review and stakeholder consultation.

[666] European Heat Pump Association. (2020). The European Heat Pump Market and Statistics Report 2020.

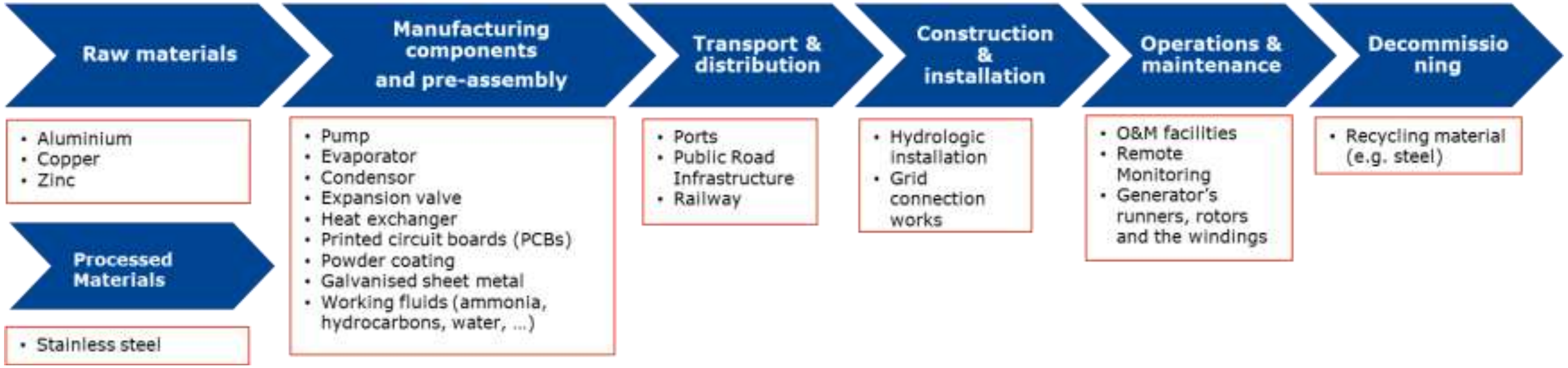
Figure 5-53 Vulnerability in the heat pump technology supply chain

	Supply chain stage	Vulnerable element	Import dependency	Market concentration	Easy of substitutability	Price stability
			Import reliance	CR4 / Main suppliers	Qualitative analysis	Coefficient of variation
Heat Pumps	Row/ processed materials	**Aluminim**	64%	79%(AU, CN, GN, BR)	Medium by cooper	22%
		Copper	42%	58%(PL, CL, PE, ES)	Medium, by aluminium	42%
		Zinc	60%	64%(CN, AU, PE, US)	For corrosion protection Zi coating is substituted by Al alloys (less effective), Cd, paint and plastic coatings (less durable)	40%
		Stainless steel	42% (tubular) Net importer in 2018	44% (Extra-EU) (RU, TR, CN, UK)	NA	21%
	Components / Equipment / Assembly	**Printed Circuit Boards**		NA	NA	NA

None of the elements appear to be vulnerable according to the assessment of these criteria, and both the literature and the stakeholders lead to the same conclusion. However, these criteria should only be considered as a preliminary assessment of the vulnerability of the elements, which is refined with other information sources.

Figure 5-54 illustrates the Heat Pump value chain.

Figure 5-54 Supply chain components of heat pumps



*Note: vulnerable elements found highlighted in **bold***

Based on the analysis of the supply elements (detailed next and summarised in Figure 5-54), none of the elements were identified as highly vulnerable. More detailed information is provided below:

Raw and processed materials

Heat pumps are made of different types of metal. Copper or aluminium tubing, critical ingredients in many heat pump components, provide superior thermal properties and a positive influence on system efficiency. Various components in a heat pump will differ depending the application, but usually they are comprised of stainless steel and other corrosion-resistant metals.

Self-contained units that house the system will usually be encased in sheet metal that is protected from environmental conditions by a paint or powder coating.

The encasements, the metal that envelopes most outdoor units, is made of galvanized sheet metal that uses a zinc coating to provide protection against corrosion.

Heat pumps may contain several raw materials categorised as critical. [667] Raw materials like vanadium and phosphorous are in some designations of steel used as alloying elements. These alloying elements are not included in this assessment as they are very difficult to quantify and more obvious choices are present such as:

- Printed circuit boards which may contain several critical materials such as gold, silver, palladium, antimony, bismuth, tantalum etc.[668]
- Compressor, tubing and heat exchangers which may contain copper
- Wires which may contain copper

Frequently, plastic and other non-traditional materials are used to reduce weight and cost.

The working fluid, the fluid that circulates through the air-conditioning system, is typically a liquid with strong thermodynamic characteristics like HFC, CFC, HCFC, ammonia, or water.

Components manufacturing and integration

Components

All heat pumps have four basic components: a pump, an evaporator, a condenser, and an expansion valve. All have a working fluid and an opposing fluid medium as well.

Overview: HP market in the EU

The European heat pump industry is a well-established economic sector and a world leader in highly efficient heat pump systems. The European heat pump sector is characterised by a few, mostly large corporations and a relatively small ecosystem with some innovative SMEs.

The European HP manufacturing sector comprises major world known names in heating (Nibe Industrier, BDR Thermea, Bosch Thermotechnology, Viessmann, etc.), but also global and major European refrigeration and air-conditioning players that have taken up positions in the heating market segment such as Japan's Daikin Industries and Mitsubishi Electric, France's CIAT.

These major groups tend to deploy their business across several brands, as a result of their intense historical M&A activity, with a few major consolidations having taken place these lats years.

In 2018, the German group Stiebel Eltron took over Danfoss Varmepumpar AB. Stiebel Eltron aims to develop its business in other markets dominated by glycol water/water heat pumps through this acquisition. Consolidation continued in 2020 with the Swedish company NIBE Industrier AB acquiring the German heat pump manufacturer Waterkotte.

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[667] Air conditioners and comfort fans, Review of Regulation 206/2012 and 626/2011 Final report

[668] Wrap. (2014). Techniques for Recovering
Printed Circuit Boards (PCBs). Available at:
https://archive.wrap.org.uk/sites/files/wrap/Techniques%20for%20recovering%20printed%20circuit%20boards,%20final.pdf

Figure 5-55 Representative Heat Pump Companies in EU (Eurobserver, 2020)[669]

Representative Heat Pump Companies in the European Union.*

Group	Brand	Country
BDR Thermea	De Dietrich	France
	Sofath	France
	Chappée	France
	Remeha	Netherlands
	Oertli Thermique	France
	Brotje	Germany
Bosch Thermotechnology	Bosch	Germany
	Buderus	Germany
Daikin Industries	Daikin Europe	Belgium
	Rotex	Germany
Atlantic	Atlantic, Atlantic-Fujitsu (co-branding)	France
Nibe Industrier AB	Nibe Energy System	Sweden
	CTC	Sweden
	Technibel	France
	KNV	Austria
	Alpha-Innotec	Germany
	Waterkotte	Germany
Vaillant Group	Vaillant	Germany
	Saunier Duval	France
Viessmann Group	Viessmann	Germany
Stiebel Eltron	Stiebel Eltron	Germany
	Thermia	Sweden

* Non-exhaustive list. Source: EurObserv'ER 2020.

According to a Global Heat Pumps Market report 2020 (United States, Europe and China)[670], Daikin, Mitsubishi and Atlantic captured the top three revenue share spots in the Heat Pumps market in 2015.

Patents and publication activity

As illustrated by Figure 5-56, Chinese patents and utility models are pulling the global patenting activity growth rate, while Europe and the rest of the world show constant or negative trends.

Figure 5-56 Yearly volume of patent inventions (2005-2015)[671]

However, for the 2010-2015 period, only 26% of the Chinese inventions were of high quality. North America leads on patent portfolio quality with 77%, followed by Asia-Pacific (excluding China) and Europe, both scoring 51%.

[669] EurObservÉR. (2020). Heat Pumps Barometer. Available at: https://www.eurobserv-er.org/pdf/eurobserver-heat-pumps-barometer-2020/

[670] Mordor Intelligence. (2020). HEAT PUMPS MARKET - GROWTH, TRENDS, COVID-19 IMPACT, AND FORECASTS (2021 - 2026). Available at: https://www.mordorintelligence.com/industry-reports/heat-pumps-market

[671] Source from EIT InnoEnergy. (2018). Top 10 Innovators: Heat pumps. Available at: https://cdn2.hubspot.net/hubfs/3416096/Top%2010%20reports/09_Heat%20pumps%20%7C%20Top%2010%20innovators.pdf

Of the top 10 players from Europe, Stiebel Eltron and Robert Bosch are the most prominent, with the highest number of inventions.[672] Siemens, Électricité de France, Robert Bosch, Vaillant, ATLANTIC Climatisation & Ventilation SAS and Viessmann Group are active since 2010, with a high quality patent portfolios. Grundfos Management has been less active in Europe since 2010, despite having high-quality inventions.

According to BusinessWire, the industrial HP market is already concentrated, and will accelerate in the coming years. The major market participants are Daikin Industries Ltd., Danfoss AS, Emerson Electric Co., Johnson Controls International Plc, Lennox International Inc., Mitsubishi Electric Corp., NIBE Industrier AB, Rheem Manufacturing Co., Robert Bosch GmbH, and United Technologies Corp.[673]

Evidence of short-term vulnerability to the COVID-19 pandemic

The heat pump supply chains did no face specific impacts due to the COVID-19 crisis.

[672] EIT InnoEnergy. (2018). Top 10 Innovators - Heat pumps. Available at: https://cdn2.hubspot.net/hubfs/3416096/Top%2010%20reports/09_Heat%20pumps%20%7C%20Top%2010%20innovators.pdf

[673] Businesswire. (2020). COVID-19: Global Industrial Heat Pumps Market 2020-2024 | Growing Focus on High-temperature Heat Pumps to Boost Market Growth | Technavio. Available at: https://www.businesswire.com/news/home/20200903005133/en/

5.12. Digital technologies for the energy sector

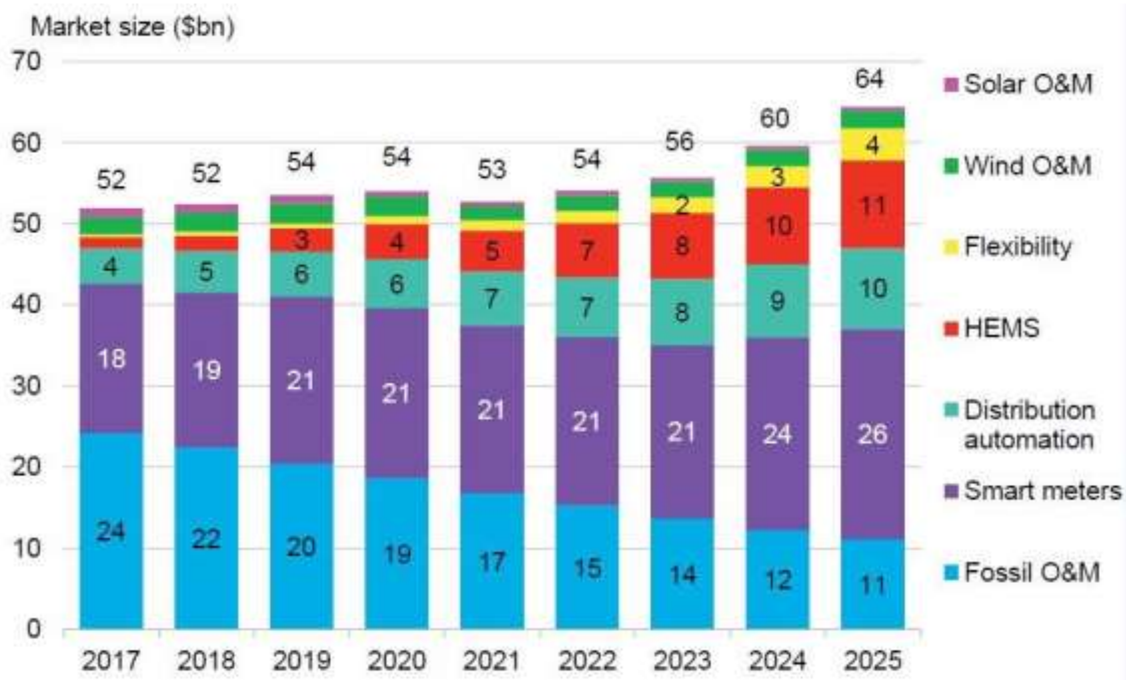
Introduction and technology description

This analysis focuses on the supply chain of ICT, sensoring, metering and control technologies employed in the energy sector, and related cyber security / data access aspects. For brevity, ICT, sensoring, metering and control technologies are hereafter named 'digital technologies'. Digital technologies employed in the energy sector encompass a wide range of elements, from end-point systems and components for energy supply, transport and storage to consumption to the digital systems to ensure the reliable operation of electricity, gas and heat networks as well as of oil & gas production.

The energy sector is critical to the economy and society as a whole[674], and digital technologies are increasing in importance for all energy supply, transport, storage and consumption technologies. While the energy sector has historically adopted digital technologies early on, digital technologies and components such as smart meters and sensors are being increasingly deployed across the energy sector, replacing analog solutions. Energy technologies enabled by digital solutions, such as autonomous cars, smart buildings or distributed energy generation, are poised to revolutionise the energy sector. Digitalisation is required for integrated energy systems and for many related new market elements, such as shorter-term energy markets, increased participation of demand response and aggregator business models. Moreover, digital technologies themselves consume energy, and data networks and centres represent today around 2% of electricity demand – although future trends are uncertain, and depend on the level of deployment and energy efficiency gains made. [675]

Energy sector investments in digital technologies already amount to over 50 billion USD and are poised to grow to up to 64 billion USD by 2025. BNEF estimates that the largest investments in 2025 will be for smart meters (26 billion USD), home energy management systems (11 billion USD), fossil energy supply (11 billion USD) and distribution automation (10 billion USD), as shown in Figure 5-57.[676] In the electricity sector, the value chain stage with the most mature application of digital technologies is transmission, while generation, distribution and consumption are in an early stage.[677]

Figure 5-57 Market size for digital technologies in the energy sector[678]



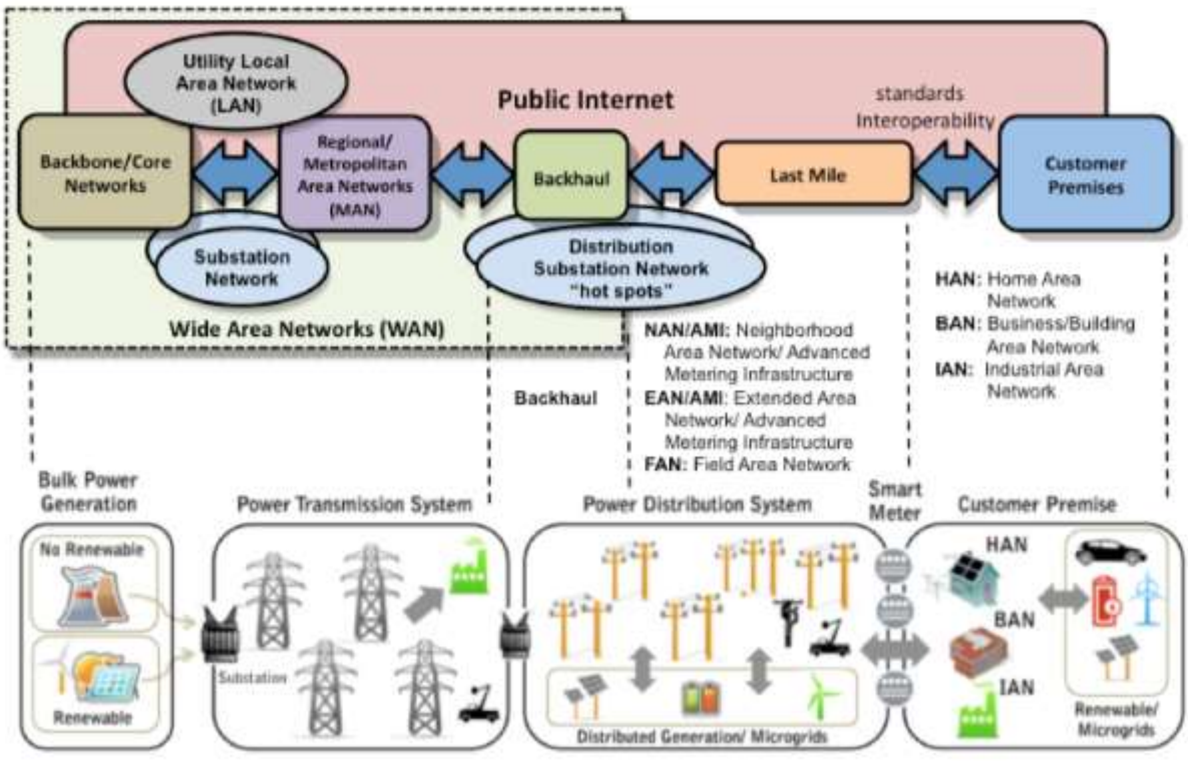
[674] Energy Expert Cyber Security Platform. (2017). Cyber Security in the Energy Sector - Recommendations for the European Commission on a European Strategic Framework and Potential Future Legislative Acts for the Energy Sector.
[675] IEA. (2017). Digitalization & energy; European Commission - EU-wide Cybersecurity legislation: Report on the implementation of the EU rules in the energy sector.
[676] BNEF. (2017). Market for Digitalization in Energy Sector to Grow to $64BN by 2025.
[677] IRENA. (2019). Enabling Technologies: Innovation Landscape briefs.
[678] BNEF. (2017). Market for Digitalization in Energy Sector to Grow to $64BN by 2025.

There is no commonly agreed framework for categorising the different digital technology components, equipment and services employed in the energy sector. Regarding digital solutions for grid operations and the integration of renewables, the European Commission indicates that "the market consists of different technologies and services in a value chain that is difficult to separate clearly, which seem to be integrating as the need increases for integrated solutions to manage storage, demand response, distributed renewables and the grid itself."[679]

Nonetheless, the high level systems involving digital technologies for the energy sector can be divided between industrial control systems, end-point systems and communications networks. Industrial control systems (ICSs) are "general term describing industrial automation systems responsible for data acquisition, visualization and control of industrial processes, often found in various industrial sectors and Critical Infrastructures. They play a critical role not only in maintaining the continuity of industrial processes but also to ensure functional and technical safety, preventing large industrial accidents and environmental disasters".[680] Energy and distributed energy resources management systems[681] could be categorised as industrial control systems or separately. End-point systems are the (group of) equipment and appliances at an energy end-user, e.g. a smart home energy system or an EV. These systems are interconnected by communications network, composed of the communication infrastructure and their control systems. Figure 5-58 presents the main communication networks relevant to smart grids. Beyond smart grids, this overall structure can be applied to e.g. gas transportation systems or oil and gas production.

A number of components and equipment is used in ICS, end-point systems and communication networks. Programmable logical controllers (PLCs) serve to supervise and control specific physical components. Remote transmission units may be used to communicate with SCADA systems and other components. Smart meters and sensors are other important digital components in the energy system. Human-machine interfaces are employed for the interaction of users with the industrial control and end-point systems. Each of these components, in turn, are composed of numerous electronic components, including electronic boards. Figure 5-60 structures these and other digital technologies elements employed in the energy sector..

Figure 5-58 End-to-End smart grid communications architecture[682]



[679] See European Commission. (2020). SWD(2020) 953.Clean Energy Transition – Technologies and Innovations.
[680] ENISA. (2015). Analysis of ICS-SCADA Cyber Security Maturity Levels in Critical Sectors.
[681] European Commission. (2020). SWD(2020) 953.Clean Energy Transition – Technologies and Innovations.
[682] ENISA. (2017). Communication network interdependencies in smart grids.

The supply chain of digital technologies for the energy sector

An analysis of supply chain elements (summarised in Figure 5-59) was conducted to identify potentially vulnerable elements. The selection of the highly vulnerable elements is based on the assessment presented in the figure, but also on the literature review and stakeholder consultation. Some elements may appear to be highly vulnerable according to the assessment of these criteria, but for several other reasons (e.g. limited amount needed), both the literature and the stakeholders do not lead to the conclusion they should be considered as such.
Therefore, these criteria (Figure 5-59) should only be considered as a preliminary assessment of the vulnerability of the elements, which is refined with other information sources

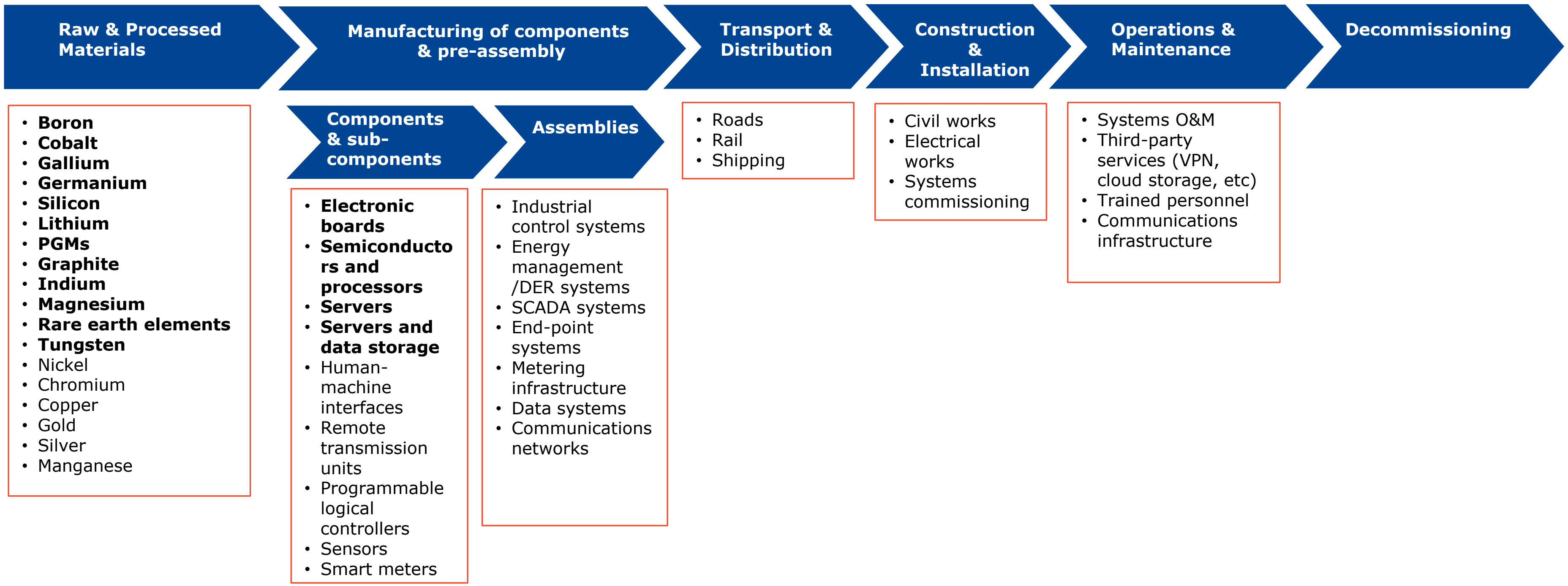
Considering this, the following elements are identified as vulnerable: several raw materials (B, Co, Ga, Ge, In, Li, Mg, graphite, platinum-group metals, rare earth elements, Si, W) and electronic boards, semiconductors and processors, and servers and data storage equipment. Moreover, the cyber-security of digital technologies is an important potential vulnerability and is analysed in more detail in different supply chains of this study (e.g. gas infrastructure, electricity networks and smart buildings). Vulnerable elements are highlighted in bold in Figure 5-60, which presents an overview of the smart buildings technology supply chain.

Figure 5-59 Vulnerabilities in the supply chain of digital technologies for the energy sector

	Supply chain stage	Vulnerable element	Import dependency	Know-how/specialisation	Market concentration	Easy of substitutability	Price stability
			Import reliance	Patents share / other	CR4 / Main suppliers	Qualitative analysis	Coefficient of variation
Digital Technologies	Raw / processed materials	Boron	100%	NA	99% (TR, AR, NO, BO)	Low	NA
		Cobalt	86%	NA	92% (CD, FI, GF, RU)	Medium	52%
		Graphite	98%	NA	67% (CR3) (CN, BR, NO)	Low	NA
		Gallium	31%	NA	94% (DE, UK, CN, US)	Low	NA
		Germanium	31%	NA	89% (FI, CN, UK, RU)	Medium	~14% (4 years)
		Silicon metal	63%	NA	68% (NO, FR, CN, BR)	Low	~10-15% (4 years)
		Lithium	100%	NA	93% (CL, US, RU, CN)	Medium	NA
		PGMs	98%	NA	96% (platinum) (ZA, RU, ZW, CA)	Medium	34% (Platinum)
		Indium	0%	NA	72% (FR, BE, UK, DE)	Low	NA
		Magnesium	100%	NA	99% (CN, UK, IL, RU)	Medium	~10% (4 years)
		Tunsten	>70%	NA	88% (CN, VN, US, RU)	Low	NA
		Nickel	59%	NA	59% (CN, RU, JP, CA)	Medium	50%
		Chromium	66%	NA	86% (ZA, TR, KZ, IN)	Low	Overall increase from 2012 to 2017
		Copper	44%	NA	58% (PL, CL, PE, ES)	Medium, by aluminium	42%
		Gold	NA	NA	37% (CN, AU, RU, US)	Varies per application	48%
		Silver	40%	NA	54% (MX, PE, CN, AU)	Varies per application	54%
		Manganese	89%	NA	62% (NO, ES, ZA, FR)	Low	Lost ~25% of its value through 2018
		Light rare earth elements	100%	NA	100% (neodymium) (CN, UK)	Low	~20% (4 years)
		Heavy rare earth elements	100%	NA	100% (dysprosium) (CN, UK)	Low	
	Components / Equipment / Assembly	Electronics	>45%	20-30% EU MSs share of EPO patent applications from top 10 countries	>40% (CN)	NA	NA
		Embedded electronics	EU manufactures 23% of global production (leading with US)		80% (EU, US, JP, CN)	NA	NA
		Industrial electronics	EU manufactures 20% of global production		CN (24%), EU (20%), US/CA (19%)	NA	NA
		Sensor systems or power electronics	EU companies are significant players		NA	NA	NA
		Electronic boards	EU companies manufacture only 10% of global production		NA	NA	NA
		Semiconductors and microprocessors	EU companies manufacture only 9% of global production		73% (TW, KR, JP, US)	NA	NA
		Servers and data storage	Majority of manufacturers and production capacity based outside of the EU		6 main manufacturers worldwide	NA	NA
		Programmable logic controllers	Leading EU position		NA	NA	NA
		Electronic components, materials & tools	EU manufactures 16% of global production		NA	NA	NA
		VPP software	Leading EU position		90% (CH, DE, UK, FR)	NA	NA
		DER management systems	Leading EU position		80% (US, FR, DE, CH)	NA	NA
		DER analytics	EU companies are significant players		~60% (CH, US, DE)	NA	NA
		ADMS	Leading EU position		High concentration	NA	NA
		Predictive maintenance	EU companies are significant players		Incipient market	NA	NA

Notes: CR4 – concentration ratio of 4 largest suppliers; PGM – platinum group metals. Sources: Eurostat PRODCOM/COMEXT; JRC (2020) Study on the EU's list of Critical Raw Materials; DG TRADE (2020) Trade policy reflections beyond the COVID19 outbreak; European Patent Office (2020) Patent statistics; DECISION for DG CONNECT (2020) Study on the Electronics Ecosystem; FastMarkets for price data of certain raw materials; other sources listed in section. **Due to the complexity of the supply chain and elements, there are overlaps between the elements presented.**

Figure 5-60 The supply chain of digital technologies for the energy sector[683]



*** Overall potential cyber vulnerability in supply chain components for the energy sector / service providers**

Note: vulnerable elements found highlighted in ***bold***.

[683] Kumara et al. (2020). Electrical Characterization of a New Crosslinked Copolymer Blend for DC Cable Insulation.

The analysis of elements of the supply chain of digital technologies for the energy sector, in particular vulnerable elements highlighted in bold in Figure 5-60, is detailed below.

Raw and processed materials

Vulnerabilities in raw and processed materials will become important if the EU develops its manufacturing capacity for digital technologies components. As currently the EU is highly dependent on foreign suppliers for such components, disruptions in the supply of critical raw and processed materials will impact the EU indirectly, through its suppliers.[684]

The JRC foresight study on critical raw materials[685] identifies 12 (categories of) raw materials used in digital technologies: boron, cobalt, gallium, germanium, graphite, indium, lithium, magnesium, PGMs, rare earth elements, silicon and tungsten. Rare earth elements have the highest supply risk, followed by magnesium, germanium and borates. The main suppliers for these materials are China (41%) and African countries (30%). The study notes on one hand that the digital technologies demand growths at an accelerated pace and that the sector innovation cycles are markedly shorter than in other technology sectors, but that on the other hand substitution dynamics mean that demand for certain critical raw elements may stagnate or even decrease, depending on the importance of the difference drivers.

Hardware and software development and deployment

Digital technologies component supply and assembly

Digital technologies can be separated in hardware and software, although both are highly interrelated. The EU is a net importer of digital technologies, with a trade deficit in 2017 of 23 billion €, mainly due to imports from China. Generally the EU is highly dependent on East Asian countries for the supply of electronic boards, semiconductors and microprocessors. This dependence exposes the EU to intentional or unintentional disruptions in the supply of digital technologies but also of the required spare parts. The EU has a significant participation in the global production of digital components such as embedded electronics, sensor systems or power electronics (e.g. 23% for embedded electronics), but produces only 10% of the world's electronic boards and 9% of its semiconductors and microprocessors.[686] The Asia Pacific region is responsible for over 60% of the global semiconductor production, and the US is a leader in semiconductors design. Taiwan, South Korea, Japan and the US are leaders in wafer production, and South Korea and US companies leaders in semiconductors production. This highlights that the EU is dependent on external, non-EU suppliers for semiconductors. These are an essential element for all electronic equipment, be it stand-alone or embedded. [687] The main EU suppliers of electronic boards[688] in 2018 were China, Taiwan, Thailand and Hong Kong, with 82% of exports to the EU then, while major suppliers of electronic integrated circuits[689] are Taiwan, Malaysia, China and the United States, accounting for 66% of the EU imports in 2018.

As part of the 2021 update of the EU Industrial Strategy,[690] the Commission conducted an in-depth review of a number of areas strategic for Europe, including semiconductors. It confirms that "the EU is strongly dependent on the US for general design tools and on Asia for advanced chip fabrication".[691]

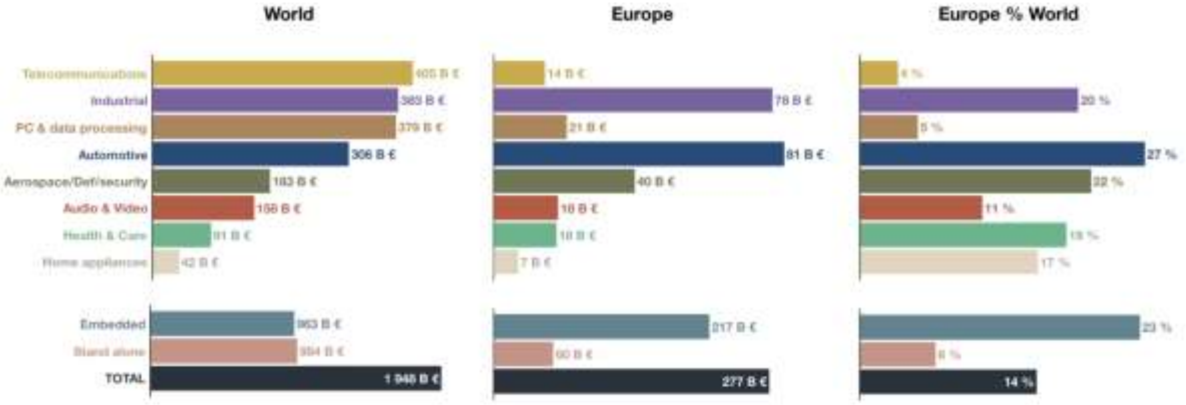
According to the Commission Impact Assessment for ecodesign requirements on servers and data storage products[692], the main manufacturers of data servers and storage equipment "include HPE (Hewlett Packard, US), Dell (US), Lenovo (China), IBM (US), Cisco (US) and Fujitsu (Germany/[Japan]). Hitachi also manufactures data storage products. There are also three other large Chinese manufacturers, which do not yet have significant European market share but may grow in future, Huawei, Inspur and Sugon. Fujitsu has manufacturing facilities in

684 European Commission. (2020). Critical Raw Materials for Strategic Technologies and Sectors in the EU - A Foresight Study. Available at: https://ec.europa.eu/docsroom/documents/42881
685 Ibid.
686 Ibid.
European Political Strategy Centre. (2019). Rethinking Strategic Autonomy in the Digital Age. Available at: https://op.europa.eu/nl/publication-detail/-/publication/889dd7b7-0cde-11ea-8c1f-01aa75ed71a1/language-en/format-PDF/source-118064052
687 DECISION for DG CONNECT. (2020). Study on the Electronics Ecosystem. Available at: https://op.europa.eu/nl/publication-detail/-/publication/8e442825-493f-11ea-b81b-01aa75ed71a1/language-en
688 CN code 8534 – printed circuits
689 PRODCOM code 26113006
690 European commission. (n.d.). European industrial strategy. Available at : https://ec.europa.eu/growth/industry/policy_en
691 European Commission. (2021). SWD(2021) 352 final. Strategic dependencies and capacities.
692 European Commission. (2019). SWD(2019) 106. Impact assessment accompanying the Commission Regulation laying down ecodesign requirements for servers and data storage products. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52019SC0106

Augsburg, Germany, which produces up to 950 servers and storage products daily, that equals to approx. 250,000 units in a year. Hitachi assembles storage products in the Netherlands and Lenovo has also disclosed plans to manufacture in Europe." Moreover, "Contract Manufacturers are used by the majority of the large vendors. The main CMs are Hon Hai, Inventec, Wistron and Quanta, all Taiwanese companies. They are increasingly involved in the design of sub-assemblies, particularly the motherboard, and have started to design and sell products directly. Their manufacturing bases include Eastern Europe (mainly Czech republic), China and Mexico." Therefore, most of the main and contract manufacturers for data servers and storage equipment are non-EU companies, with most manufacturing capacity also located outside of the EU. Indeed, the EU is responsible for the production of around 4% of the global telecommunication equipment manufacture. [693]

The EU is a leading player in some electronic segments (see figures below), namely industrial (20% share of global production), automotive (27%) and embedded electronics (23%).[694] On industrial electronics, it is a particular leader on factory automation (19% of the global production in 2016), test and measuring (30%), power applications (22%) and transportation (33%). It also has an important share (16%) of the global production of electronic components, materials and tools.

Figure 5-61 Production of electronic equipment by segment in 2017 (M€)



Source: DECISION for DG CONNECT (2020) Study on the Electronics Ecosystem

The EU is a leading player in the programmable logic controllers (PLC) market. Major global manufacturers comprise Schneider Electric (FR), Rockwell Automation (US), Siemens (DE), ABB (CH), and Mitsubishi (JP). According to Mordor Intelligence, the "European PLC market was valued at USD 3736.1 million in 2020 […]. Europe's higher investment levels, since 2016, in industrial IoT have made the region maintain its lead among the other regions, such as the United States and Asia."[695]

The EU27 market for electricity grid monitoring, sensors, and connected IoT devices is made up almost entirely of distribution equipment, especially distribution transformer sensors and substation automation, estimated to surpass 1 100 million EUR in 2020. Major manufacturers are Hitachi (JP), ABB (CH), Siemens (DE), Itron (US) and Schneider Electric (FR)[696].

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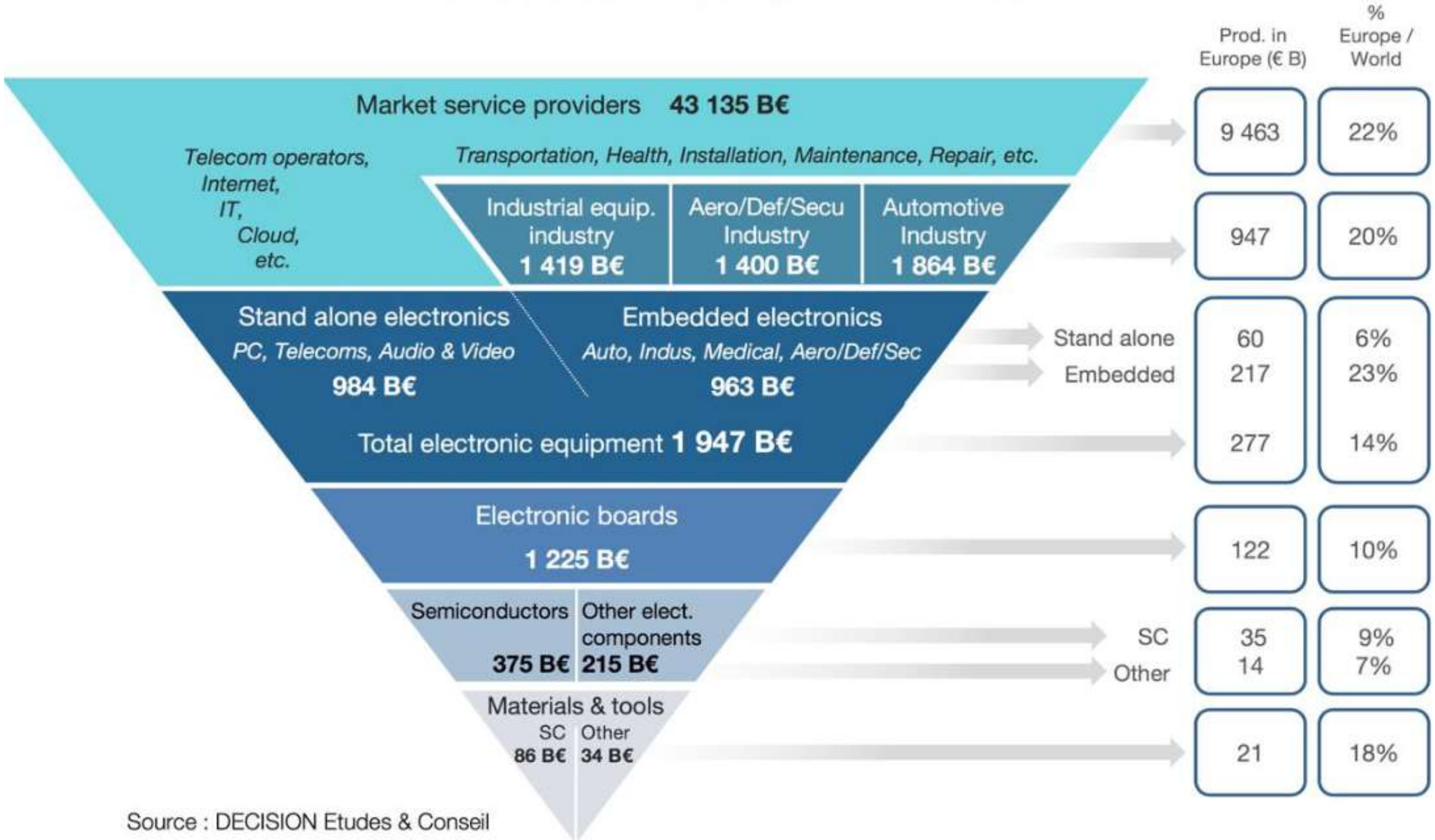
[693] DECISION for DG CONNECT. (2020). Study on the Electronics Ecosystem. Available at: https://op.europa.eu/nl/publication-detail/-/publication/8e442825-493f-11ea-b81b-01aa75ed71a1/language-en
[694] Ibid.
[695] Mordor Intelligence. (2021). Europe Programmable Logic Controller (PLC) Market - Growth, Trends, COVID-19 Impact, and Forecasts (2021 - 2026)
[696] European Commission. (2020). SWD(2020) 953. Clean Energy Transition – Technologies and Innovations. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0953

Figure 5-62 Worldwide electronics value chain 2017



Source: DECISION for DG CONNECT (2020) Study on the Electronics Ecosystem

Software for the energy sector

The market for energy management and related software is highly concentrated, with European players having a strong position for many software categories. Nonetheless, certain markets for energy sector software may still be incipient (for example software platforms for predictive maintenance), or with a limited participation of European suppliers (for example home energy management systems).

Regarding various energy management and industrial control systems, Europe made in 2018 152 million EUR of public and private investments for managing virtual power plants (VPPs), against 446.3 million EUR for the rest of the world (RoW). Major VPP software suppliers are ABB (CH), Next Kraftwerke (DE), Centrica (UK) and Schneider Electric (DE). [697]

For distributed energy resources (DER) management systems European investments amount to 65 million EUR (against 102.3 million EUR for the RoW). Major DER management system suppliers are GE (US), Schneider Electric (FR), Siemens (DE), ABB (CH) and OSI (US). [698]

The EU investments in DER analytics software are more modest, at 37.8 million EUR (against 140.1 million EUR for the RoW). The market for DER analytics is more fragmented, with the major suppliers being Landis+Gyr (CH), Itron (US), Siemens (DE), Oracle (US) and GE (US). Hence, EU investments in DER management systems and VPP software are particularly important compared to the RoW.[699]

The EU has the highest penetration of advanced distribution management systems (ADMS) in the world, with higher rates of deployment observed in Western European network operators. The market is concentrated, with the main suppliers being GE (US), Schneider Electric (FR), Oracle (US), Siemens (DE), ABB (CH) and ACS-Indra (ES).

Software platforms for predictive maintenance are an additional software category, incipient with an EU27 market size of around 90 million EUR but with strong growth forecasts. Major manufacturers are Hitachi (JP), ABB (CH), IBM (US), Schneider Electric SE (FR), Oracle (US), GE (US), Siemens (DE), and C3.ai (US).[700]

Supply chain-related cyber threats

In addition to the dependence on foreign suppliers of digital technologies, the energy sector may also be vulnerable to cyber threats. Out of the various cyber security issues which should be considered, the ones related to supply chains comprise the:[701]

- **Integrity of digital technology components and their supply chain, i.e. [702]:** unintentional vulnerabilities may not be identified and corrected on time, or backdoors or hidden functions may be embedded in digital components used in the energy sector or to provide services to it. Zero-day vulnerabilities or backdoors can be employed later on by malicious actors to compromise (segments of) the energy sector;
- **Outsourcing of infrastructures and services**: 3rd party data services and telecommunication networks may have lower reliability requirements, and be a target of cyber attacks which can then disrupt the energy sector or provide a point of entry to energy companies.

Reliance on domestic or foreign digital technologies suppliers can effectively expose critical EU digital and energy infrastructure to cyber attacks[703], if there is not an effective management system to minimise risks that hardware and software employed in the EU energy sector are compromised due to e.g. backdoors inserted in the upstream supply chain in ‘black box’ components (software, hardware of bundled products comprising both). The importance of the upstream supply chain for

[697] European Commission. (2020). SWD(2020) 953. Clean Energy Transition – Technologies and Innovations. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0953
[698] Ibid.
[699] Ibid.
[700] Ibid.
[701] European Commission. (2021). EU-wide Cybersecurity legislation: Report on the implementation of the EU rules in the energy sector
[702] Public-Private Analytic Exchange Program (2017) Supply Chain Risks of SCADA/Industrial Control Systems in the Electricity Sector: Recognizing Risks and Recommended Mitigation Actions
[703] A number of other cyber security aspects beyond supply chains-related ones should be considered but are not analysed here. The Directive on Security of Network and Information Systems (EU) 2016/1148 provides cybersecurity provisions applying to multiple sectors, including the energy sector. See also European Commission (2019) EU-wide Cybersecurity legislation: Report on the implementation of the EU rules in the energy sector

smart grids cyber security has been highlighted for some time - a Commission Expert Group[704] indicated in 2013 that "process should be implemented for information systems acquisition, development and maintenance." Smart grids supply chain management is an analysis topic also by the EU Agency for Network and Information Security (ENISA).[705] An example of supply-chain related cyber attack in the energy sector due to the supply chain of digital technologies is the exploit of a bug on Citrix Systems (a VPN solutions provider) software, requiring customers to address potential vulnerabilities, including one Dutch network operator.[706] A very recent and extremely serious one is the SolarWinds incident, detailed in Textbox 2-2 in chapter 2. Beyond the energy sector, a number of software or hardware supply chain-based attacks can be identified in the last years.[707]

The integrity of digital energy technologies supply chains and the outsourcing of digital infrastructure and services are concrete vulnerabilities of the EU energy system. Despite the recognition in EU-level documents of these vulnerabilities, there seems to be at the EU level limited concrete actions to address the issue. The Commission Expert Group indicated in 2017 that "a supply chain and integrity framework is not available today" and recommends the Commission "to establish supply chain integrity framework for components and suppliers, used in processes handled by operators of essential services for energy, via a contractual public private-partnership (cPPP)".[708] The 2019 Commission recommendation on cybersecurity in the energy sector[709] does not explicitly address the integrity of digital technology components and their supply chain. In the Netherlands, Dutch energy sector companies have conducted a study on "Cyber security supply chain risk analysis", providing a methodology to identify related risks.[710]

The importance of cyber vulnerabilities of digital technologies depends on the energy supply chain they are employed and the number of devices deployed. Electricity and gas systems have been highlighted as strategic due to the systemic impact of disruptions. Nuclear energy generators are also strategic from a safety perspective.[711] However, while isolated compromised end-point devices such as home routers may not impact the overall energy system, as these end-point devices may employ common hardware, software and protocols, they may be vulnerable to attacks affecting thousands or more devices, leading to a significant impact to ICT or energy systems. Hence, systemic risks arise not only from vulnerable critical, centralised components but also vulnerable distributed devices whose systemic disruption may have large-scale impacts. [712]

Other countries and regions face similar supply chain vulnerability issues[713], with the topic is also gaining increasing attention. The US appears to have taken more concrete measures compared to the EU. In 2020 the US Executive Order (EO) 13920 - Securing the United States Bulk-Power System[714] was issued, addressing specifically the digital technologies supply chains vulnerabilities related to the power system. Following this, the US Department of Energy issued a request for information on related vulnerabilities, best practices and needs, receiving 98 contributions.[715] A recent study developed recommendations on potential areas for action regarding the Executive Order.[716] The Report on Sectorial implementation of the NIS Directive[717] in the Energy sector identifies

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704 Expert Group on the Security and Resilience of Communication Networks and Information Systems for Smart Grids (2017) Cyber Security of the Smart Grids – Summary Report

705 ENISA. (2017). Communication network interdependencies in smart grids.

706 Gasunie. (2020). 2020 half-year report. Available at: https://www.gasunie.nl/en/about-gasunie/investor-relations/financial-information/$5762/$5763

707 Microsoft. (2018). Software supply chains at risk, in Microsoft security intelligence report;
European Political Strategy Centre. (2019). Rethinking Strategic Autonomy in the Digital Age.

708 Expert Group on the Security and Resilience of Communication Networks and Information Systems for Smart Grids. (2017). Cyber Security in the Energy Sector - Recommendations for the European Commission on a European Strategic Framework and Potential Future Legislative Acts for the Energy Sector.

709 C(2019) 2400 final. Commission Recommendation on cybersecurity in the energy sector. Available at: https://ec.europa.eu/energy/sites/ener/files/commission_recommendation_on_cybersecurity_in_the_energy_sector_c2019_2400_final.pdf

710 Shell, Gasunie, Nuon, TenneT and Alliander (2015) Cyber security supply chain risk analysis

711 European Commission. (2021). EU-wide Cybersecurity legislation: Report on the implementation of the EU rules in the energy sector. Available at: https://digital-strategy.ec.europa.eu/en/library/eu-wide-cybersecurity-legislation-report-implementation-eu-rules-energy-sector

712 European Political Strategy Centre. (2019). Rethinking Strategic Autonomy in the Digital Age. Available at: https://op.europa.eu/nl/publication-detail/-/publication/889dd7b7-0cde-11ea-8c1f-01aa75ed71a1/language-en/format-PDF/source-118064052

713 Ibid.

714 Federal Register. (2020). Securing the United States Bulk-Power System.
https://www.federalregister.gov/documents/2020/05/04/2020-09695/securing-the-united-states-bulk-power-system

715 Regulations.gov. (2020). Securing the United States Bulk-Power System. Available at:
https://beta.regulations.gov/document/DOE-HQ-2020-0028-0001

716 Stockton. (2020). Securing the grid from supply-chain based attacks.

717 NIS Cooperation Group. (2019). Sectorial implementation of the NIS Directive in the Energy sector.

the following North American standards specific to supply chain vulnerabilities for digital technologies:

- Electricity sector: North American Reliability Council CIP-013-1 Cyber Security – Supply Chain Risk Management
- Gas sector: Oil and Natural Gas Subsector Cybersecurity Capability Maturity Model (ONG-C2M2)

Foreign ownership of digital technologies companies is also a relevant question gaining increased attention. The JRC calculates over a quarter of Chinese direct investments in the EU are related to next generation IT technologies. [718] However, while China has a strong focus on the sector, the US and Canada have a more important foothold on relevant EU sectors, owning around 45% of EU electronic components manufacturing assets and 41% for communication equipment manufacturing assets. US and Canada acquired 36 companies in the two sectors in 2015-2017, against 11 by China. Around 54% of the assets in the EU for the manufacture of computer, electronic and optical products in 2016 were foreign-owned.[719]

Operation and maintenance

When discussing maintenance supply chain aspects, the cyber security literature usually focuses on the need for maintaining software systems up-to-date (using the latest versions), conducting vulnerability tests (e.g. to detect potential system devices which may be visible on public networks) and managing supply chain relationships so hardware, software and services suppliers promptly identify, communicate and address vulnerabilities and security breaches. The relevant aspects related to the sourcing of equipment and outsourcing of digital infrastructure and services are analysed above.

The availability of qualified workers is a challenge to the EU energy sector. The European Commission indicates "IT literacy and [the] ability to utilise new digital technologies" as specific challenges which currently affect the EU clean energy sector.[720]

Evidence of short-term vulnerability to the COVID-19 pandemic

COVID-19 impacted the supply chain of electronic manufacturers. According to a survey by IPC, an international industry association for PCBs and electronics manufacturers, already in March 2020 69 of respondents indicated their suppliers were communicating delays in shipments due to COVID-19. However, consumer electronics were expected to be the most impacted, only then followed by industrial and automotive electronics.[721] In Europe, a survey by DIGITALEUROPE conducted in March-April 2020 indicates that while supplies to the European digital industry from China were the most affected (86% of deliveries, of which 11% were discontinued and 31% highly limited), intra-European supplies were affected almost as much, with 74% of deliveries affected (1% discontinued and 16% highly limited). Supplies from the US and South Korea were also affected significantly (62% and 71% with some sort of disruption, respectively).[722] A survey by the IEA in May 2020 indicated that respondents considered that COVID-19 supply chain disruptions was only somewhat likely to hinder R&D in energy sector digitalisation.[723]

The COVID-19 crisis also provides new opportunities for malicious actors to conduct success cyber attacks. The increase in remote work can lead to increased vulnerability and also an accelerated connection of systems which were historically isolated, or whose connection progressed at a slower pace, such as energy networks control centres.[724] However, no specific case of a disruption of the EU energy system due to cyber attacks exploiting digital technologies supply chain vulnerabilities arising from COVID-19 were identified.

[718] European Political Strategy Centre. (2019). Rethinking Strategic Autonomy in the Digital Age.
[719] European Commission (2019). SWD(2019) 108. Foreign Direct Investment in the EU.
[720] See European Commission. (2020). COM(2020) 953.Report on progress of clean energy competitiveness.
[721] IPC. (2020). The Impact of the Coronavirus (COVID-19) Epidemic on Electronics Manufacturers:march Update. Available at https://www.ipc.org/emails/gr/corona-virus-report2.pdf
[722] DIGITALEUROPE. (2020). Pan-European survey on the impact of COVID-19 on the digital industry. Available at https://www.digitaleurope.org/resources/pan-european-survey-on-the-impact-of-COVID-19-on-the-digital-industry/
[723] IEA. (2020). Energy Technologies Perspectives 2020 – Special Report on Clean Energy Innovation
[724] ECHO network. (2020). The COVID-19 Hackers Mind-set; World Economic Forum. (2020). Why COVID-19 is making utilities more vulnerable to cyberattack - and what to do about it.

6. ANNEX C: ASSUMPTIONS AND CALCULATIONS ON THE STRATEGIC IMPORTANCE OF SUPPLY CHAINS

This annex provides for each supply chain listed in section 1.1 the assumptions, calculations and sources employed to calculate the strategic importance indicators.

The sources and assumptions are, except when indicated otherwise:

- Current share: 2015 data for the supply chain/technology and final energy consumption (FEC) from the Long-Term Strategy.[725] For end-use sectors (transport and buildings) the sectoral final energy consumption is used;
- Future share: 2050 data for the supply chain/technology and final energy consumption (FEC) from the 1.5TECH scenario of the Long-Term Strategy.[726] For end-use sectors (transport and buildings) the sectoral final energy consumption is used;
- Flexibility provision: Considers the following contributions in the 2050 METIS1.5TECH scenario of the Energy Storage Study:
    - Capacity provision in the 100 hours with the highest energy supply scarcity (i.e. with the highest residual demand – the demand minus the renewable electricity supply), relative to the total capacity provision in those hours;
    - Flexibility provision relative to the total in the daily and seasonal horizons.

Table 6-1 Details on the calculation of the strategic importance indicators for all supply chains

Supply chain/technology		Current share	Future share (2050)	Flexibility provision	Qualitative aspects	Additional sources
Energy supply						
Electricity	Wind – onshore/offshore	LTS 2015: wind provides 9% of elec x 22% elec share in FEC	LTS Decarb2050: wind provides 26% of elec x 50% elec share in FEC			
	Solar PV	Solar PV provided 9.5 Mtoe of electricity in 2018	LTS Decarb2050: Solar PV provides 16% of elec x 50% elec share in FEC			Eurostat nrg_bal_c
	Concentrated solar power	JRC: CSP exceed 2 GW in the EU (average capacity factor of 32%), to a FEC of 1086 Mtoe in the LTS 2015.	JRC: CSP could reach 28 GW in the EU (average capacity factor of 32%), to a FEC of 684 Mtoe in the LTS 1.5TECH.			
	Hydropower	LTS 2015: hydro produces 29 Mtoe, to a FEC of 1086 Mtoe	LTS 1.5TECH: Generation in LTS 2030 (32 Mtoe) scaled up to 2050 considering the increase in 'other renewables' installed capacity, subtracting biomass capacity (60 GW in 2030, 80 GW in 2050) . Compared to a FEC of 684 Mtoe in the LTS 1.5TECH.	Some provision of capacity in top 100 scarcity hours and daily and seasonal flexibility (~2-3% of total) in Energy Storage study		

[725] European Commission. (2018). 'In-depth analysis in support of the Commission Communication COM(2018)773 A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy'. Available from: https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/long-term_analysis_in_depth_analysis_figures_20190722_en.pdf
[726] Ibid.

Supply chain/technology		Current share	Future share (2050)	Flexibility provision	Qualitative aspects	Additional sources
	Ocean energy	Marginal contribution to electricity supply	No significant contribution indicated in LTS			Ocean Energy Europe (2020) Key trends and statistics 2019
	Geothermal – for power	0.86 Mtoe electricity production in LTS 2015 to a FEC of 1086 Mtoe	1.6 Mtoe electricity production in LTS baseline to a FEC of 881 Mtoe			
	Nuclear fission	73 Mtoe electricity production in LTS 2015 to a FEC of 1086 Mtoe	13% of electricity production in LTS 1.5TECH x 50% elec share in FEC	Some provision of capacity in top 100 scarcity hours and seasonal flexibility (~6% of total) in Energy Storage study	High share of the electricity supply for some Member States.	
	CCGT/OCGT	530 Mtoe electricity production in LTS 2015 to a FEC of 1086 Mtoe	LTS 1.5TECH: Generation in LTS 2030 (673 Mtoe) of fossil fuels (with and without CCS) scaled down to 2050 1.5 TECH proportional to reduced installed capacity. Compared to a FEC of 684 Mtoe in the LTS 1.5TECH.	Some capacity provision (5-6% of total) in top 100 scarcity hours in Energy Storage study		
	Coal (conventional / advanced / IGCC)	68 Mtoe electricity production in LTS 2015 to a FEC of 1086 Mtoe	Marginal energy supply in LTS 1.5TECH		Not strategic to long-term policy goals	
Heat	Geothermal – for heat	20 Mtoe energy supply in LTS 2015 minus 1.1. Mtoe of produced electricity, to a FEC of 1086 Mtoe	19 Mtoe energy supply in LTS baseline minus 1.5. Mtoe of produced electricity, to a FEC of 881 Mtoe			
	Solar Thermal	2.2 Mtoe energy supply in 2018, to a FEC of 1115 Mtoe				Solar Heat Europe (2019) Solar Heat Markets in Europe
	Waste heat recovery	1.1 Mtoe waste heat supply in 2015 (top 14 MS) to a FEC of 1086 Mtoe	LTS: 22 Mtoe savings in all scenarios due to waste heat recovery, compared to a FEC of 684 Mtoe in the LTS 1.5TECH.			Heat Roadmap Europe 4 (2018) Summary tables and figures
Other supply	Fossil-based energy supply + CCU/S	Marginal use for energy supply	LTS 1.5TECH: 16.7 GW of installed capacity with capacity factor of 80%, to a FEC of 684 Mtoe in the LTS 1.5TECH.			E3M et al. (2018) ASSET study - Technology pathways in decarbonisation scenarios
	BECCS	No BECCS employed currently for energy supply in the EU	LTS 1.5TECH: 49.1 GW of installed capacity with capacity factor of 80%, to a FEC of 684 Mtoe in the LTS 1.5TECH.			E3M et al. (2018) ASSET study - Technology pathways in decarbonisation scenarios

Supply chain/technology		Current share	Future share (2050)	Flexibility provision	Qualitative aspects	Additional sources
	Biomass CHP (all biomass forms)	LTS 2015: provides ~6% of elec x 22% elec share in FEC	LTS baseline: provides ~6% of elec x 50% elec share in FEC	Some provision of capacity in top 100 scarcity hours and daily and seasonal flexibility (~4-5% of total) in Energy Storage study		
	Other CHP	50 Mtoe of energy (electricity + heat) from fossil CHP in LTS 2015, to a FEC of 1086 Mtoe	No significant contribution indicated in LTS for 2050			Eurostat Combined Heat and Power (CHP) data 2005-2018
	Biomass – liquid fuels	16.4 Mtoe in LTS 2015, to a FEC of 1086 Mtoe	40.7 Mtoe in LTS 1.5TECH, to a FEC of 684 Mtoe			
	Biomass – gaseous fuels	15 Mtoe in LTS 2015, to a FEC of 1086 Mtoe	71 Mtoe in LTS 1.5TECH, to a FEC of 684 Mtoe	Significant provision of capacity in top 100 scarcity hours in Energy Storage study	Can facilitate the efficient use of the current methane gases infrastructure	
	Electrolytic hydrogen	Marginal use for energy supply	77 Mtoe in LTS 1.5TECH to a FEC of 684 Mtoe	Significant provision of daily and seasonal flexibility (>50% of total) in Energy Storage study		
	Other RFNBOs	Marginal use for energy supply	45 Mtoe in LTS 1.5TECH to a FEC of 684 Mtoe	Significant provision of daily and seasonal flexibility (>50% of total) in Energy Storage study		
	Hydrogen from SMR	31 Mtoe in LTS 2015, to a FEC of 1086 Mtoe	Marginal use for energy supply			
	Other decarbonised fuels / RCF	Marginal use for energy supply	No significant contribution indicated in LTS for 2050			
	Natural gas production	72.3 Mtoe, to a FEC of 958 Mtoe for the EU27 in 2015	51 Mtoe energy supply in LTS baseline, to a FEC of 881 Mtoe			Eurostat nrg_bal_c
	Oil production	75 Mtoe in LTS 2015, to a FEC of 1086 Mtoe	2 Mtoe energy supply in LTS baseline, to a FEC of 881 Mtoe		Not strategic to long-term policy goals	
Energy transport						
Gas	Gas networks	~374 Mtoe transported in LTS 2015, to a FEC of 1086 Mtoe	~256 Mtoe transported in LTS 1.5TECH, to a FEC of 684 Mtoe	Significant provision of capacity in top 100 scarcity hours and daily and seasonal flexibility by gas-fired technologies in Energy Storage Study		

Supply chain/technology		Current share	Future share (2050)	Flexibility provision	Qualitative aspects	Additional sources
	Liquified gas terminals	83 Mtoe imported through LNG terminals in 2019, to a FEC of 983 Mtoe in the EU27	Assumes 20% of natural gas consumption of 66.6 Mtoe in LTS 1.5TECH is supplied by LNG terminals (same as in 2019), to a FEC of 684 Mtoe			Eurostat nrg_124m, nrg_bal_c ACER (2020) Wholesale gas markets MMR
Electricity	Electricity networks	~237 Mtoe transported in LTS 2015, to a FEC of 1086 Mtoe	~343 Mtoe transported in LTS 1.5TECH, to a FEC of 684 Mtoe	Significant provision of capacity in top 100 scarcity hours and daily and seasonal flexibility (>8% of total) in Energy Storage Study		
Heat & cool	District heating and cooling	46 Mtoe transported in LTS 2015, to a FEC of 1086 Mtoe	32 Mtoe transported in LTS 1.5TECH, to a FEC of 684 Mtoe			
Energy storage						
Storage	Batteries – mobile/stationary	25.8 Mtoe of storage (with pumped hydro), to a FEC of 1086 Mtoe	11 Mtoe stored and 51.9 employed in EVs in LTS 1.5TEC, to a FEC of 684 Mtoe	Provision of daily flexibility (>14% of total) by EVs in Energy Storage Study		
	Hydro pump storage	25.8 Mtoe of storage (with batteries), to a FEC of 1086 Mtoe	4 Mtoe stored in LTS 1.5TEC, to a FEC of 684 Mtoe	Significant provision of capacity in top 100 scarcity hours and some daily flexibility (~3% of total) in Energy Storage Study		
	Hydrogen storage (for electricity)	Marginal use	9 Mtoe stored in LTS 1.5TEC, to a FEC of 684 Mtoe			
	Liquid new fuels storage	16.4 Mtoe of storage, to a FEC of 1086 Mtoe	40.7 Mtoe in LTS 1.5TEC (e-liquids), to a FEC of 684 Mtoe		Limited repair needs	
	Gaseous fuels storage	25% of the 237 Mtoe of gases consumption is stored.	Assumes 25% of the 128 Mtoe of gases consumption is stored, reflecting proportion of 2015.	Some daily flexibility (>4% of total) in Energy Storage Study		ACER (2020) Wholesale gas markets MMR
	Thermal storage	Assumes storage of 20% of 46 Mtoe transported in LTS 2015, to a FEC of 1086 Mtoe	Assumes storage of 20% of 32 Mtoe transported in LTS 1.5TECH, to a FEC of 684 Mtoe			Guelpa et al. (2019) Thermal energy storage in district heating and cooling systems: A review. Applied Energy 252.
Energy consumption						
Transport	Battery EVs/recharging stations/smart charging/V2G	4.8 Mtoe of total 360.8 Mtoe transport energy consumption in LTS 2015	51.9 Mtoe of total 200.6 Mtoe transport energy consumption in LTS 1.5TECH	Provision of daily flexibility (>14% of total) by EVs in Energy Storage Study		

Supply chain/technology		Current share	Future share (2050)	Flexibility provision	Qualitative aspects	Additional sources
	Fuel cell vehicles/HRFs	Marginal use	31.7 Mtoe of total 200.6 Mtoe transport energy consumption in LTS 1.5TECH	Provision of daily flexibility (>14% of total) by EVs in Energy Storage Study		
Buildings	Smart buildings & automation (incl. HVAC)	Marginal use	Considers 36 Mtoe/a of savings due to smart buildings technologies, to a FEC in residential and tertiary sectors of 384 Mtoe in the LTS baseline	Provision of daily flexibility (~16% of total) by EVs and heat pumps (enabled by smart buildings) in Energy Storage Study		Vito et al. for DG ENER (2018) Smart Readiness Indicators for Buildings study
	Heat pumps	9.9 Mtoe heat supply in 2016 to a FEC in residential and tertiary sectors of ~452 Mtoe	Heat pumps (individual and district heating) can supply up to 100 Mtoe, to a FEC in residential and tertiary sectors of 384 Mtoe in the LTS baseline	Provision of some daily flexibility (~2% of total) in Energy Storage Study		Heat Roadmap Europe 4 (2018) Summary tables and figures
	Efficient appliances and equipment	164 Mtoe/a of energy savings achieved by eco-design regulations by 2020, to a FEC in residential and tertiary sectors of 481 Mtoe in 2020	Can contribute to up 11% of buildings energy savings to 2050		Passive as achieved efficiency gains are maintained after installation, broad range of technologies	CE Delft for ECF (2020) Zero Carbon Buildings 2050
	Building shell	NA	Can contribute to up 39% of buildings energy savings to 2050 in ECF scenario		Passive as achieved efficiency gains are maintained after installation, broad range of technologies	CE Delft for ECF (2020) Zero Carbon Buildings 2050
Enabling technologies						
Enabling	Digital technologies	Limited but growing in importance.	Assessed as being an enabler of digitalisation for all energy sector assets			IEA (2017) Digitalization & energy IRENA (2019) Enabling Technologies: Innovation Landscape briefs

7. Annex D: Further elaboration on the hazards per threat scenario

Threat scenario: Extreme weather events

Climate change refers to a long-term alteration to the weather patterns over a longer period of time. Anthropogenic climate change can result in increased frequency, intensity and duration of extreme weather events. These extreme weather events could compromise the functioning of different stages of the energy technology supply chains. The risks due to extreme weather events to energy supply chains are highly plausible, and there is a need to plan for agile and adaptive responses. This is highlighted in a study done by the World Energy Council, which presented the learnings from 10 previous extreme weather events experienced around the world[727]. A study by the JRC analyses the resilience of large investments and critical infrastructures in Europe to climate change and highlights the increased frequency and intensity of the extreme weather events that will occur in the coming decades.[728]

Extreme temperatures such as heatwaves

According to the European Environmental Agency (EEA), Europe has been warming up faster than the global average, and is projected to continue heating up at a rate faster than the global average in the coming century. The four warmest years in Europe recorded were in the recent years of 2014, 2015, 2018 and 2019[729].

Heatwaves could impact manufacturing and O&M in critical energy supply chains. Extreme heat can lead to disruptions across the entire supply chain where physical presence is required, as works may need to be halted, or adjusted in accordance with local workplace health and safety guidelines[730]. A period of extreme heat during a heatwave in the United States in 2019 strained transmission and distribution facilities, and the reduced reliability and performance of the energy supply chains as a result of extreme temperatures[731]. Heatwaves may require adjusted maintenance schedules, e.g. to clear up electricity transmission lines corridors. Heatwaves can also affect transport capacity by road and rail, potentially leading to delays in deliveries (which could possible be manageable).

Extreme heat also affects the performance of energy assets (which is out of scope of this study). For example, solar PV cells would be less efficient in warmer temperatures. Nuclear plants could be forced to temporarily shut down or to curtail their output due to unsafe levels of heat[732], especially for nuclear plants that rely on river water to cool down their reactors as they have to comply with the allowable temperature to return the water into the river[733]. High temperatures and heat waves limit the efficiency and capacities of transmission lines, due to increased energy losses and sagging.

Extreme rainfall resulting in flooding events

Changes in precipitation patterns in Europe is less spatially coherent than temperature trends. The majority of Scandinavia and the Baltic states have observed increases in annual precipitation over the past decades, while southern Europe has experienced decreases. The trends for precipitation in southern Europe tends to decrease while northern Europe increases in both summer and winter seasons[734].

Extreme rainfall could disrupt the supply of material flows as seaports and land transport infrastructure such as roads and railways are closed or damaged. Infrastructure damages can restrict access to energy plants or production sites, which could disrupt the various stages of the supply chains simultaneously, including manufacturing, construction and installation as well as operations

[727] World Energy Council. (2019). Dynamic Resilience to Extreme Weather. Available at https://www.worldenergy.org/transition-toolkit/dynamic-resilience-framework/extreme-weather
[728] JRC (2015) Resilience of large investments and critical infrastructures in Europe to climate change
[729] European Environmental Agency. (2020). Available at https://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-10/assessment
[730] Australian example. https://www.ohsrep.org.au/heat
[731] E&E News. (2019). Heat wave slams the grid. Here's what to know. Available at https://www.eenews.net/stories/1060771407
[732] Reuters. (2019). Available at https://www.reuters.com/article/us-france-electricity-heatwave-idUSKCN1UK0HR
[733] Qvist, Staffan. (2019). Available at https://energyforhumanity.org/wp-content/uploads/2019/08/Qvist-Nuclear-and-Heat-Waves-August-2019-FINAL_.pdf
[734] EEA. (2017). Mean precipitation. Available at https://www.eea.europa.eu/data-and-maps/indicators/european-precipitation-2/assessment

and maintenance[735]. However, different freight transport modes also have different vulnerabilities. The COVID-19 pandemic also had an impact on freight, which saw a reduced capacity of air freight and shipping. Land transport, mainly in intra-EU freight, also saw initial delays due to border controls. However, long-distance trans-Eurasian rail lines, such as the rail network between EU and China have shown to be resilient to pandemic scenario[736], although it may be vulnerable to delays in an extreme weather event such as extreme rainfall.

High-intensity hurricanes

High-intensity hurricanes can lead to forced closure or restricted operations of plants and production sites as the extreme weather condition can be unsafe for workers to leave home. Transportation of freight can also be limited or completely disrupted as well. This can lead to downstream consequences, reducing the supply of raw and processed materials, thus affecting manufacturing, construction and installation works, or even the operations and maintenance of energy supply chains.

High-intensity hurricanes can be disruptive to physical infrastructure, which could severely limit the functioning of energy supply chains across the supply chain stages of materials supply, manufacturing construction and installation as well as operations and maintenance. The EEA projects that the occurrence, and severity of winter storms in Europe will increase over the 21st century[737]. While Europe does not frequently experience hurricanes, Hurricane Ophelia which hit the Republic of Ireland in 2017 highlighted the risks and impacts exposed to the energy supply chains in such an extreme weather event – 360,000 households experienced power disruptions[738]. Other world regions such as the gulf of Mexico and East Asia are subject to hurricanes and significant suppliers to EU energy technology supply chains such gas production and networks or digital technologies.

Threat scenario: Cyber threats

Digital technologies are increasing in importance for all energy supply, transport, storage and consumption technologies. While the energy sector has historically adopted digital technologies earlier, newer digital technologies and components such as smart meters, sensors, programable logical controllers and SCADA systems are being extensively deployed across the energy sector, replacing analog solutions. Energy technologies enabled by digital solutions, such as autonomous cars, smart homes and machine learning, are poised to revolutionise the energy sector. The transport, buildings and end-use sectors will be thus strongly impacted, while oil, gas, gas and electricity supply could have their costs reduced and potential resources increased with digitalisation. Digitalisation is required for integrated energy systems and for many related new market elements, such as shorter-term energy markets, increased participation of demand response and aggregator business models. Moreover, digital technologies themselves consume energy, and data networks and centres represent today around 2% of electricity demand – although future trends are uncertain, and depend on the level of deployment and energy efficiency gains made.[739]

The rise of digitalisation in the energy sector has been accompanied by an increase in the number of cyber threat actors targeting the energy sector, which reached around 155 groups in 2019 – almost double the number in 2014.[740] Some of the attack strategies may target the energy technology supply chains. The potential scale of disruption of the energy technology supply chains due to cyber vulnerabilities is dependent on several factors, including:

- whether the energy supply chains employ digital technologies and the extent to which they are employed, such as the number of devices deployed;
- the energy technology that is attacked. For example, the vulnerabilities of the electricity and gas systems to cyber attacks have been highlighted as critical due to the systemic impact of potential disruptions. The Directive on European Critical Infrastructures provides an initial indication of energy technologies which are considered critical and could thus lead to the systemic disruption of the energy system. These include electricity (generation, transmission and distribution), oil (oil production, refining, treatment, storage and transmission by pipelines) and gas infrastructure (gas production, refining, treatment, storage and

[735] McKinsey Global Institute. (2020). Could climate become the weak link in your supply chain? Available at https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability/Our%20Insights/Could%20climate%20become%20the%20weak%20link%20in%20your%20supply%20chain/Could-climate-become-the-weak-link-in-your-supply-chain-v3.pdf
[736] EURNEX. (2020). Impact on the transport sector – Europe. Available at http://www.eurnex.org/wp-content/uploads/2020/06/COVID_Rail_AT.pdf
[737] EEA. (2017). Wind storms. Available at https://www.eea.europa.eu/data-and-maps/indicators/storms-2/assessment
[738] BBC. (2017). Hurricane Ophelia: Three people die as storm hits Ireland. Available at https://www.bbc.com/news/uk-41627442
[739] IEA. (2017). Digitalization & energy; European Commission - EU-wide Cybersecurity legislation: Report on the implementation of the EU rules in the energy sector.
[740] World Energy Council. (2019). Cyber challenges to the energy transition.

transmission by pipelines). Cyber security for nuclear energy generators are extremely important from a safety perspective.[741] The compromise of isolated end-point devices such as home routers may not impact the overall energy system, although collectively, thousands or more of these end-point devices may be susceptible to a wide-scale attacks as they employ common hardware, software and protocols. This can lead to a significant impact to ICT or energy systems. Hence, systemic risks arise not only from the vulnerability of critical, centralised components but also from distributed devices where systemic disruption may lead to large-scale impacts. [742] Wind technology has also been identified by the US Department of Energy as a probable target for threat actors, disrupting or damaging wind turbines through unauthorised access of SCADA systems[743].

- The motivations behind malicious cyber activities by different threat actor(s). Figure 7-1 provides some examples of the type of malicious activities that can be taken by various threat actors, along with their motivations and goals of launching such attacks.

Figure 7-1 Examples of malicious activities by different threat actors (Source: European Systemic Risk Board, 2020[744])

Cyber risk: threat actors, motivations and goals

Threat actor	Motivations	Goals	Examples
Nation-states, proxy groups	Geopolitical, ideological	Disruption, destruction, damage, theft, espionage, financial gain	Permanent data corruption Targeted physical damage Power grid disruption Payment system disruption Fraudulent transfers Espionage
Cybercriminals	Enrichment	Theft/financial gain	Cash theft Fraudulent transfers Credential theft
Terrorist groups, hacktivists, insider threats	Ideological, discontent	Disruption	Leaks, defamation Distributed Denial of Service (DDoS) attacks

Sources: ESRB, MI5 and Cambridge Centre for Risk Studies.

While operators of critical energy assets are aware of the risks in networking control systems for e.g. energy networks and nuclear power plants, there are advantages of doing so. Additionally, it may occur due to other factors, such as the need for remote working due to COVIDCOVID-19. Therefore, other hazards may compound the cyber vulnerabilities of the energy system.

Other countries and regions face similar cybersecurity issues related to supply chains[745], with the topic gaining increasing attention. In 2020 the US Executive Order (EO) 13920 - Securing the United States Bulk-Power System[746] was issued, addressing specifically the digital technologies supply chains vulnerabilities related to the power system. Following this, the US Department of Energy issued a request for information on related vulnerabilities, best practices and needs, receiving 98 contributions.[747] A recent study developed recommendations on potential areas for action regarding the Executive Order.[748] The Report on Sectorial implementation of the NIS Directive[749] in the Energy sector identifies the following North American standards specific to supply chain vulnerabilities for digital technologies:

[741] European Commission. (n.d.). EU-wide Cybersecurity legislation: Report on the implementation of the EU rules in the energy sector. Available at: https://digital-strategy.ec.europa.eu/en/library/eu-wide-cybersecurity-legislation-report-implementation-eu-rules-energy-sector
[742] European Political Strategy Centre. (2019). Rethinking Strategic Autonomy in the Digital Age
[743] U.S. Department of Energy. (2020). Roadmap for Wind Cybersecurity. https://www.energy.gov/sites/prod/files/2020/08/f77/wind-energy-cybersecurity-roadmap-2020v3.pdf
[744] European Systemic Risk Board. (2020). Systemic cyber risk. Available at: https://www.esrb.europa.eu/pub/pdf/reports/esrb.report200219_systemiccyberrisk~101a09685e.en.pdf?fdefe8436b08c6881d492960ffc7f3a9
[745] European Political Strategy Centre. (2019). Rethinking Strategic Autonomy in the Digital Age
[746] Federal Register. (2020). Securing the United States Bulk-Power System. Available at: https://www.federalregister.gov/documents/2020/05/04/2020-09695/securing-the-united-states-bulk-power-system
[747] Regulations.gov. (2020). Securing the United States Bulk-Power System. Available at: https://beta.regulations.gov/document/DOE-HQ-2020-0028-0001
[748] Stockton. (2020). Securing the grid from supply-chain based attacks.
[749] NIS Cooperation Group. (2019). Sectorial implementation of the NIS Directive in the Energy sector.

- Electricity sector: North American Reliability Council CIP-013-1 Cybersecurity – Supply Chain Risk Management
- Gas sector: Oil and Natural Gas Subsector Cybersecurity Capability Maturity Model (ONG-C2M2)

While stakeholders which provided feedback on the vulnerabilities of energy systems to cyber threats are aware of these risks, limited information has been provided on actual risks and mitigation actions being taken related to the supply chain. Hence, supply chain-related cybersecurity may still be undervalued by actors in the energy system. Despite the recognition in EU-level documents of these vulnerabilities, there seems to be limited concrete actions at the EU level to address the issue. The Commission Expert Group indicated in 2017 that "a supply chain and integrity framework is not available today" and recommends the Commission "to establish supply chain integrity framework for components and suppliers, used in processes handled by operators of essential services for energy, via a contractual public private-partnership (cPPP)".[750] The 2019 Commission recommendation on cybersecurity in the energy sector[751] does not explicitly address the integrity of digital technology components and their supply chain, but the preparatory work undertaken for establishing a Network code for the security of cross-border electricity flows considers this aspect. In the Netherlands, Dutch energy sector companies have conducted a study on "Cybersecurity supply chain risk analysis", providing a methodology to identify related risks.[752]

Out of the various cybersecurity issues which should be considered, the ones related to supply chains comprises of the:[753]

- **Integrity of digital technology components and their supply chain, i.e.** [754]**:** unintentional vulnerabilities may not be identified and corrected on time by technology suppliers, or backdoors or hidden functions may be embedded in digital components used in the energy sector. These vulnerabilities or backdoors can be employed later on by malicious actors to compromise (segments of) the energy sector;
- **Outsourcing of infrastructures and services**: 3rd party data services and telecommunication networks may have lower reliability requirements, and be a target of cyber attacks which can then disrupt the energy sector or provide a point of entry to energy companies.

These are disaggregated and further detailed in the following section.

Unintentional vulnerabilities in hardware/software

Malicious actors could exploit unintentional vulnerabilities in hardware and software employed in the energy sector. Zero-day vulnerabilities are vulnerabilities of which the technology vendor is unaware of. After its discovery, vendors usually provide security patches and mitigation actions users can take until the vulnerability is fully resolved. Vulnerabilities can still be exploited after their discovery by the vendor, until they are patched or addressed otherwise (e.g. by replacing products). If technology vendors are not pro-active in informing users of the vulnerability and providing solutions, this could expose segments of the energy sector.

Lack of timely updates/patches

The lack of a systematic patch management also contributes to a heightened risk of cyber attacks. Without regular updates, and/or processes which test the effect of the patches before installation can cause the system to be compromised and/or destabilised. Additionally, installing patches may not straightforward as energy systems operate real-time.[755] [756]Therefore, energy companies lacking adequate processes to prevent and detect unintentional vulnerabilities in their products , and/or are too slow to react to any vulnerabilities could compromise the wider system of the energy sector.

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[750] Expert Group on the Security and Resilience of Communication Networks and Information Systems for Smart Grids (2017) Cybersecurity in the Energy Sector - Recommendations for the European Commission on a European Strategic Framework and Potential Future Legislative Acts for the Energy Sector

[751] European Commission. (2019). Commission Recommendation on cybersecurity in the energy sector C(2019) 2400 final. https://ec.europa.eu/energy/sites/ener/files/swd2019_1240_final.pdf

[752] Shell, Gasunie, Nuon, TenneT and Alliander. (2015). Cybersecurity supply chain risk analysis. https://www.cybersecurityraad.nl/binaries/Cybersecurity_supply_chain_risico-analyse_ENG_tcm107-323429.pdf

[753] European Commission. (2021). EU-wide Cybersecurity legislation: Report on the implementation of the EU rules in the energy sector. Available at: https://digital-strategy.ec.europa.eu/en/library/eu-wide-cybersecurity-legislation-report-implementation-eu-rules-energy-sector

[754] Public-Private Analytic Exchange Program. (2017). Supply Chain Risks of SCADA/Industrial Control Systems in the Electricity Sector: Recognizing Risks and Recommended Mitigation Actions.

[755] IEA. (2017). Digitalisation and energy.

[756] https://ec.europa.eu/energy/topics/energy-security/critical-infrastructure-and-cybersecurity_en

Backdoors / hidden functions in hardware / software

In addition to unintentional vulnerabilities, although more rarely, backdoors in hardware and/or software can permit threat actors[757] to bypass normal authentication or encryption and allow for unauthorised access to system networks remotely. These vulnerabilities can be inserted in vendor hardware or software of suppliers, allowing to compromise users of these products or services. The SolarWinds incident described in Textbox 2-2 illustrates this case. Similarly, hidden functions (product capabilities which are disabled as e.g. the user has not paid for the function, such as Wi-Fi capability in remote terminal units) could be employed by adversaries to access digital components. With this access, the users will have the capacity to tamper with and jeopardize digital systems.
Both unintentional vulnerabilities as well as backdoors and hidden functions can originate upstream in the supply chain. The importance of the upstream supply chain for e.g. smart grids cybersecurity has been highlighted for some time - a Commission Expert Group[758] indicated in 2013 that "process should be implemented for information systems acquisition, development and maintenance." Smart grids supply chain management is also an analysis topic by the EU Agency for Network and Information Security (ENISA).[759] A gas TSO indicates that the standard ISO/IEC 27001 already requires suppliers to provide self-disclosure on cybersecurity/information security. An effective management system with strong involvement of suppliers is required to minimise risks that hardware and software employed in the EU energy sector are compromised.

Large-scale deployment of end-point digital equipment in the energy sector

Digitalisation and automation of the energy sector will be integral to the transition towards clean energy, which includes the expansion of smart grids, the roll-out of smart meters, the increasing usage of industrial control and energy management systems for energy supply, transport, storage and end-use, and the multiplication of the number of smart equipment and appliances. As the size, complexity and the interconnectedness of the digital energy network increases, so does the risk of cyber attacks on the energy sector as it increases the access points which may be exploited. In addition, the use of open-source software and protocols has been increasing, for example in home energy management systems. While open source software brings about many advantages, just like any other software, it may be exposed to vulnerabilities, and can compromise systems[760]. Finally, end-users employing home energy management systems and smart equipment and appliances may not be aware of the cybersecurity risks nor have sufficient knowledge to mitigate them. Hence, while decentralization and digitalization has great potential to develop the energy sector, they also come with heightened security risks to the entire energy sector, especially in energy end-use.

Vulnerabilities of 3rd party service providers

In addition, as it is becoming increasingly common for actors in the energy sector to contract services from third party providers, it also increases the risk of exposure of the energy sector to cyber vulnerabilities. Service providers can be an important source of cyber vulnerability in the energy sector, especially for small and medium enterprises who may outsource more digital services and lack the necessary processes to address vulnerabilities. Managing third-party cyber security risks are therefore important.

The main services that are contracted can comprise ICT infrastructure (communication networks, servers), cloud storage and virtual private network capability. Hence, even if an energy company's ICT and industrial control systems are secure, these third party service providers may still lead to those being compromised. For example, targeting cloud service providers was a successful strategy in a 2018 attack which impacted the oil, gas and electricity sectors in the US.[761] In addition, strategies not related to the supply chain can also be used to attack service providers (such as phishing), which increases the number of potential vulnerabilities in the energy technologies supply chains.

Threat scenario: Geo-political tension

The EU Commission acknowledges the vulnerabilities that the EU faces with its dependency on third countries for primary and secondary materials. In September 2020, the EU Commission presented an Action Plan on Critical Raw Materials[762], which identifies the current and future challenges to the

[757] Which includes cybercriminals, industrial spies, state-sponsored hackers, intelligence agencies and military cyber commands. European Parliament (2019) Cybersecurity of critical energy infrastructure
[758] Expert Group on the Security and Resilience of Communication Networks and Information Systems for Smart Grids (2017) Cybersecurity of the Smart Grids – Summary Report
[759] ENISA. (2016). Communication network interdependencies in smart grids. https://www.enisa.europa.eu/publications/communication-network-interdependencies-in-smart-grids
[760] For example the Equifax security breach incident in 2017 which affected about 143 million US citizens. https://www.synopsys.com/blogs/software-security/what-caused-equifax-breach/
[761] Deloitte. (2018). Managing cyber risk in the electric power sector.
[762] European Commission. (2020). COM(2020) 474 final. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability.

supply of raw materials. The plan proposes, among others, to reduce dependency on third countries, and to diversify sources of supply. The European Commission, as well as the World Bank, foresee an increase in the demand for raw materials as EU pursues its climate-neutrality goals. For example, the EU would need up to 18 times more lithium and 5 times more cobalt in the next decade, and about double the amounts in 2050. Demand for rare earths used in permanent magnets for use in electric vehicle, ICT, or wind generators could also increase tenfold by 2050.

Moreover, EU businesses are also dependent on third countries for a number of equipment, components and software, including solar PV cells, Li-ion battery cells, nuclear reactor parts, electronic components, and home energy management software. Often, global markets for these elements are highly concentrated, given the knowledge required and manufacturing economies of scale.

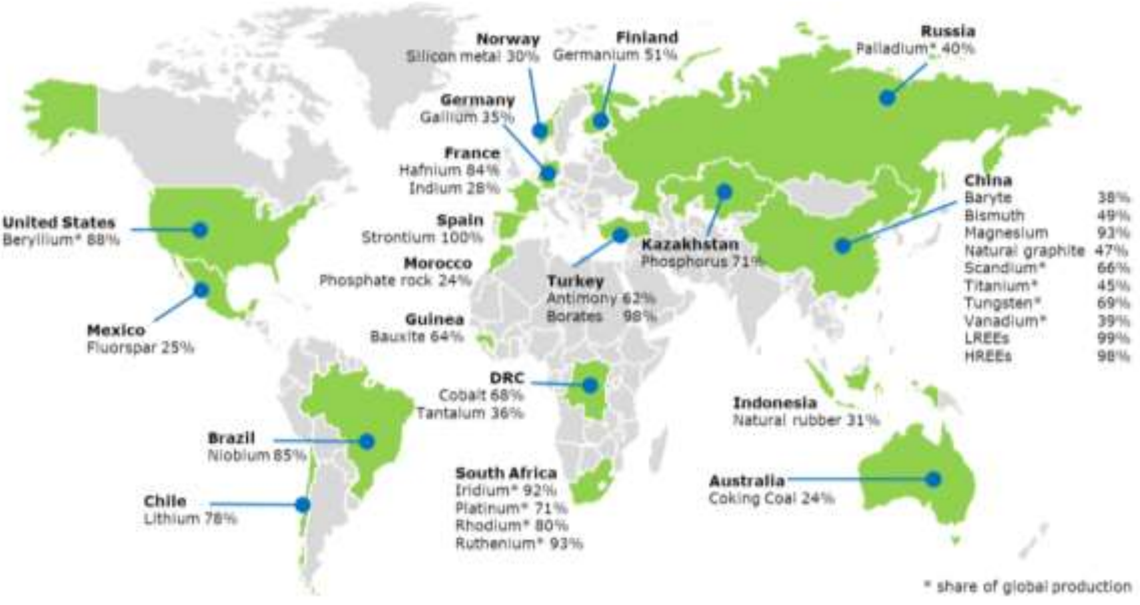
Therefore, the EU's dependence on specific countries and regions for the supply of raw materials as well as equipment and components may lead to disruptions should geo-political tensions arise between EU and third countries, and due to political instability in certain regions. This instability may also affect supply routes.

Disruptions to supply routes

The transition to clean energy will require critical raw materials to develop new infrastructure. The dependence of the EU on the supply of many critical raw materials is highly concentrated, as illustrated in Figure 7-2. Any disruptions to the supply route as a result of geo-political tensions could pose as significant risks for EU's future security of energy supplies. For example, the maritime route from between North America, Pacific Asia and Europe passes through several chokepoints such as the Panama Canal, Suez Canal, and the Strait of Malacca, as shown in Figure 7-3. These 'chokepoints' are key locations in the global trade of goods. Although alternative shipping routes are available, there are limited cost-effective alternatives should there be any disruption due to geopolitics, or other factors, and could potentially lead to significant increases in logistical costs and delivery times.

In addition to the possibility of disruptions in the maritime routes, the geopolitics of air travel could also disrupt the delivery of materials, which may include highly sensitive parts which are managed in global warehouses, ready to be shipped overnight where needed. The bulk of air freight passes mainly through the airports located in Europe, the United States, Middle-East, and Asia[763]. The concentration of air freight handling in these three regions also increases the risks and vulnerability faced by the EU. Any disruptions which could arise from local political instability, and/or geo-political tensions of these regions with the EU, could result in disruptions in the supply of materials, and/or increase the price of logistics.

Figure 7-2 Countries accounting for largest share of EU supply of Critical Raw Materials. Source (European Commission, n.d.)[764].



[763] International Airport Review. (2020). The top 20 busiest airports in the world by cargo handled. Available at https://www.internationalairportreview.com/article/107921/top-20-busiest-airports-world-cargo/
[764] European Commission. (n.d.). Critical raw materials. Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Figure 7-3 Main maritime shipping routes and chokepoints[765]

Increases in trade tariffs and other trade measures taken by the EU or other countries

A number of trade measures can be taken by the EU to promote a level-playing field between EU and foreign economies. The analysis below presents the potential impacts that such measures could have on energy technology supply chains. However, other considerations are made when assessing trade measures, including providing a level playing field, (positive) impacts on the EU economy, the mitigation of carbon leakage and the protection of the environment. Therefore, we do not argue that trade measures should be avoided given potential negative impacts on the energy technology supply chains.

Trade sanctions

Due to geo-political tensions between Russia and the EU, a comprehensive package of targeted economic sanctions by the EU against Russia was adopted in 2014. Sanctions are implemented to partially or completely cut off economic, diplomatic and cultural relations[766]. These sanctions included, among others, a restriction on Russia's access to financial markets and services, as well as on products for high-technology oil exploration and production equipment[767]. This had an impact for large Russian energy firms. Such actions could also lead to price volatility of the supply of materials from Russia, which could impact downstream energy technology supply chains in the EU.

Trade sanctions which may be implemented by other regions could also have an impact on the energy supply chains in the EU. For example, in 2018, the sanctions imposed on Russia by the United States saw significant global price increases due to worries of supply shortages for the material palladium.

The impact of trade sanctions leading to disruptions in the supply of goods can be seen much in the same light as the impacts of other trade measures, such as anti-dumping tariffs – although the impacts are more severe. Trade sanctions may not only affect the capacity of EU businesses to trade with non-EU suppliers in specific countries, but also limit the provision of banking, shipping and insurance services.[768] Moreover, as illustrated by the case of palladium markets, sanctions imposed by other countries such as the US could affect prices or directly impact EU businesses which would prefer to maintain business relations with the US rather than with the sanctioned country. Therefore, the impact of sanctions can be more severe than other EU trade measures, and also affect supply chain stages such as international transport or other services required for all stages.

[765] Rodrigue, J-P et al. (2020). The Geography of Transport Systems, Hofstra University, Department of Global Studies & Geography. Available at: https://transportgeography.org.

[766] Zaynutdinov, R. R. (2015). Russia and Europe under sanctions: problems of energy development. International Journal of Energy Economics and Policy, 5(2).

[767] Other sanction also include an embargo on the imports and exports of arms and related materials, a prohibition of exports of dual use goods and technology for military use.

[768] Nephew, R. (2020). The Impact of COVID-19 on Global Supply Chains and Sanctions. Available at: https://www.energypolicy.columbia.edu/sites/default/files/file-uploads/SupplyChains+Sanctions_CGEP_Commentary_050720-2.pdf

Export restrictions imposed by major exporters

Natural resource endowments, and consequently the production of raw materials, such as minerals and other industrial raw materials, are unevenly distributed. For example, in 2012, China produced 91% of the world's supply of rare earth metals, needed for the manufacturing of hybrid electric vehicles, wind turbines, FCH and several other energy equipment. Almost 90% of the global production of platinum and related metals occurs in South Africa and in Russia. The major producers of selected raw materials are shown in Figure 7-4. The export dependency of the EU - and the rest of the world - has on these limited number of exporting countries, coupled with substitutes for these materials may not be readily available, increases the risk that the EU energy technologies supply chains face shortages and price increases should any of the producing countries apply export restrictions.

Most, if not all of these exporting countries are members of the World Trade Organisation (WTO). The WTO generally does not allow export prohibitions and restrictions other than imposing duties, taxes and other charges, although there are exceptions[769]. For example, temporary prohibitions and restrictions may be permitted to prevent or relieve critical shortages of certain products to the exporting country, such as foodstuffs or other essential products. Export restrictions on raw materials may also be imposed on several bases, including the protection of the environment and the preservation of natural resources. However, not all of these export restrictions have been implemented based on these reasons. Between 2009 and 2019, a total of six disputes have been filed with WTO regarding the export measures that have been implemented for the exportation of various raw materials, where five were filed against China, and one against Indonesia. The latest filing against China (of 2016) was filed by the EU regarding restrictions on the export of antimony, chromium, cobalt, copper, graphite, indium, lead, magnesium, talc, tantalum and tin[770]. In 2020 the European Commission informed that "after the establishment of a panel China informed the European Union that the measures which were subject to the complaint were not renewed for 2017. The Commission continues to monitor the situation in China".[771] As global demand for raw materials are expected to increase, this risk of this hazard can also increase in the future.

Figure 7-4 Major producers of minerals and metals (OECD, 2014)[772]

Product	Major producers, by share of world production (2012)	Top 5 producers' share
	Figures in parentheses are percentage shares	%
Minerals and metals		
Antimony	China (82), Tajikistan (4), Russia (4), Bolivia (3), South Africa (2)	95
Chromium	South Africa (44), Kazakhstan (20), India (12), Turkey (9), Oman (2)	87
Cobalt	Democratic Republic of Congo (68), China (5), Zambia (4), Australia (4), Cuba (3)	84
Copper	Chile (32), China (10), Peru (8), United States (7), Australia (5)	62
Iron ore	China (44), Australia (18), Brazil (13), India (5), Russia (4)	84
Lithium	Chile (49), Australia (30), Argentina (9), United States (5), China (4)	97
Nickel	Philippines (17), Russia (14), Indonesia (13), Australia (13), Canada (11)	68
Platinum group metals	South Africa (59), Russia (27), Canada (5), United States (4), Zimbabwe (4)	99
Rare earth oxides	China (91), United States (4), Australia (3), Russia (2) Brazil (0.2), Malaysia (0.1)	100
Tin	China (40), Indonesia (31), Peru (9), Bolivia (7), Brazil (4)	91
Tungsten	China (83), Russia (6), Canada (3), Bolivia (2), Rwanda (1)	95

769 WTO. (2020). Export prohibitions and restrictions: Information note. Available at: https://www.wto.org/english/tratop_e/COVID19_e/export_prohibitions_report_e.pdf

770 WTO. (n.d.). Index of disputes issues - Raw Materials. Available at: https://www.wto.org/english/tratop_e/dispu_e/dispu_subjects_index_e.htm?id=G158

771 European Commission. (2020). General overview of active WTO dispute settlement cases involving the EU as complainant or defendant, of cases under bilateral agreements and of active cases under the trade barriers regulation. Available at: https://trade.ec.europa.eu/doclib/docs/2020/october/tradoc_158960.docx

772 OECD. (2014). Export Restrictions in Raw Materials Trade: Facts, fallacies and better practices. Available at: https://issuu.com/oecd.publishing/docs/oecd-export-restrictions-raw-materi

8. Annex E: Considered policy responses

This section identifies the main possible policy response categories and the main reasons for discarding the policy response from the final policy recommendations of chapter 3. The definition of the categories considered existing industrial, trade and other regulatory instruments, as well as other measures identified in the literature or proposed by stakeholders.

Table 8-1 Potential policy responses and related existing instruments to address energy technology supply chains

	Description	Reasons to include or discard the response
1. Limiting demand for products	Limiting demand for products for which a dependency might exist or occur in the future (based on dependency foresight studies), through a legal instrument or indicative policy measures, phasing in measures according to the importance of the product for the critical supply chains in order not to cause disruptions.	Would represent strong intervention in markets, and implementation measures such as import quotas would contravene WTO rules. More positive measures such as circular economy
2. Requirements or guidelines for business sourcing processes	Requirements (mandatory) or guidelines (voluntary) for businesses sourcing products and services from the upstream supply chain, such as to assure/incentivise that suppliers have business continuity plans, measures to ensure the cyber-security of the supply chain, and others.	See Recommendation 5.
3. EU-based primary materials production incentives	Stimulating EU-based raw materials extraction, by measures such as subsidies, tax reductions, specific derogations, dedicated innovation and commercialization facilities, stimulating improved efficiency of production, recycling.	See Recommendation 3.
4. EU-based RD&I for substitution materials and technologies	Dedicated innovation and commercialization facilities for developing substitution materials and technologies.	See Recommendation 7.
5. Diversification of countries of origin and/or suppliers	Agreements with alternative non-EU countries for development of new raw material and manufacturing capacity; justified import restrictions; support for intra-EU platforms for industry developing alternative suppliers; Investments by EU companies in non-EU countries.	See Recommendations 3 and 4
6. Bilateral agreements with main supplying countries	Agreements creating balanced trade relationships and mutual dependencies with main supplying countries.	See Recommendations 3 and 4.
7. Group purchases / joint negotiation	Facilities for group purchases/joint negotiation between various Member States / EU companies.	Constitutes a strong market intervention and there is no interest from EU companies for this type of measure. Companies may adopt such initiatives voluntarily if it is in their interest, and are best placed to identify the needs and potential for group purchases / joint negotiation. This could be handled in the framework of the alliances discussed in Recommendations 2 and 3.

	Description	Reasons to include or discard the response
8. Strategic or emergency stocks for components	Minimum strategic or emergency stock requirements for energy technology industries	Constitutes a strong market intervention and probably such stock very difficult to set up as a separate response. Given innovation an emergency stock could quickly lead to obsolete equipment. A high-level obligation for critical entities to consider such requirements as one of various risk mitigation measures can be part of recommendation 5.
9. Diplomacy to secure trade routes	Agreements/negotiation with countries concerned for logistic routes chokepoints to secure stability and measures in case of disruption	See Recommendations 2 and 3.
10. Requirements for business continuity plans	Requiring energy technology industries (only critical ones, or all) to develop and maintain business continuity plans considering supply chain disruptions	See Recommendation 6.
11. Intra-EU solidarity measures	Voluntary or mandatory solidarity measures between Member States in the provision of components in case of disruptions.	Would require a high level of cross-border integration of company Enterprise Resource Planning systems / a mechanism for identification and exchange of components by market parties, being a highly complex measure with associated costs.
12. Improved price signals (energy/networks/taxation/carbon components)	Improving price signals for energy consumers providing a level-playing field for all energy technologies with the aim to develop and diversifying flexibility resources to increase the resilience of the EU energy system.	While highly relevant to maintain / develop the EU market for critical energy technologies, this is not addressed in the present study as it is out of scope.
13. Development of new standards / increased participation in standardisation bodies	Develop / improve standards on products/materials to reduce risks (e.g. to cyber threats) & possibly exclude import of non-compliant products/materials, as well increase the participation of EU organisations in international standardisation bodies.	Relevant to address e.g. cyber threats, but not selected as one of the recommendations as addressed in other studies concerning cyber-security aspects (see chapter 3 textbox).
14. EU-based assembly and production	Stimulating EU-based assembly and production through measures in similar categories as those considered in 3.	See Recommendation 4.
15. Trade defence measures	Trade defence measures to address unequal competition from non-EU suppliers, such as anti-dumping measures.	See Recommendations 2 and 3.
16. Recycling and circular economy / energy and resource efficiency	Various measures increasing material circularity and energy efficiency, including eco-design regulations and standards, labelling, sharing of best practices and industry platforms.	See Recommendations 5 and 6.
17. EU RD&I financing for low carbon technologies	EU / national RD&I support for identified critical energy technologies (complementing RD&I for substitution materials and technologies indicated above)	See Recommendation 4 and 7.

	Description	Reasons to include or discard the response
18. Strengthen cooperation at regional or sectoral level	Establish/promote regional/industry & academia cooperation platforms for the critical energy supply chains.	See Recommendations 3 and 4.
19. Cooperation through multi-lateral fora and international organisations	EU participation in fora/organisations such as WTO and the International Study Groups for specific raw materials, to raise awareness and develop measures concerning supply chain vulnerabilities concerning materials, products and services.	See Recommendations 3 and 4.
20. Monitoring most critical components (mainly raw material)		See Recommendation 1.

Green: directly addressed in the policy measure recommendations of chapter 3.
Blue: indirectly addressed in the policy measure recommendations of chapter 3.
Red: not included as a policy measure recommendation.

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