European Commission

Study on energy technology dependence

Detailed assessment on dependencies within the wind energy, solar PV and battery energy storage value chain

Independent Expert Report

Onne Hoogland (Trinomics) and Marcel Cremers (DNV GL)
February 2019

Research and Innovation

Study on energy technology dependence

European Commission
Directorate-General for Research and Innovation
Directorate Clean Planet
Unit D.1 – Clean Energy Transition
Contact Daniele Poponi
Email *RTD-ENERGY-CALL-FOR-TENDERS@ec.europa.eu*
RTD-PUBLICATIONS@ec.europa.eu
European Commission
B-1049 Brussels

Manuscript completed in February 2019

More information on the European Union is available on the internet (http://europa.eu)
Luxembourg: Publications Office of the European Union, 2020

PDF ISBN 978-92-76-14130-3 doi: 10.2777/747154 KI-04-19-769-EN-N

EUROPEAN COMMISSION

Study on energy technology dependence

Detailed assessment on dependencies within the wind energy, solar PV and battery energy storage value chain (Task 4)

Edited by

Onne Hoogland (Trinomics)
Marcel Cremers (DNV GL)
Jon Feenstra (DNV GL)
Tim van Benthem (DNV GL)
Francesca Feller (DNV GL)
Hans Cleijne (DNV GL)
Levent Küçük (DNV GL)
Valentin Doychinov (DNV GL)
Nynke Verhaegh (DNV GL)
Novy Francis (DNV GL)

Trinomics

In association with:

Ricardo Energy & Environment

DNV·GL

JIIP Joint Institute for Innovation Policy

tecnalia TNO VTT

Directorate-General for Research and Innovation
2020 Secure, Clean and Efficient Energy

TABLE OF CONTENTS

List of abbreviations

AC	Alternating current
a-Si	Amorphous Silicon
BIPV	Building-Integrated Photovoltaics
BJT	Bipolar Junction Transistor
CdTe	Cadmium Telluride
Ce	Cerium
CIGS	Copper Indium Gallium Selenium
CR4Company	Four-firm concentration ratio
CR4Country	Four-country concentration ratio
CRM	Critical Raw Material
c-Si	Crystalline Silicon
DC	Direct current
DD-PMSG	Direct-drive permanent magnet synchronous generators
DFIG	Double-fed induction generator
DRC	Democratic Republic of the Congo
Dy	Dysprosium
EBA	European Battery Alliance
EC	European Commission
EESG	Electrically excited synchronous generator
EPR	Ethylene Propylene Rubber
EU28	28 Member States of the European Union
EV	Electrical vehicle
GW	Gigawatt
GWac	Gigawatt alternating current
GWdc	Gigawatt direct current
GWh	Gigawatt hour
HVDC	High voltage direct current
IGBT	Insulated Gate Bipolar Transistor
IP	Intellectual property
kt	Kilotonne
kVA	Kilovolt-ampere
LCO	Lithium Cobalt Oxide
LED	Light-emitting diode
LFP	Lithium Iron Phosphate
Li-ion	Lithium-ion
LMO	Lithium Manganese Oxide
LTO	Lithium Titanate
m	metre
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MPPT	Maximum power point tracking
MS/HS-PMSG	Medium and high-speed permanent magnet synchronous generators
MT	Megatonne
MW	Megawatt
MWac	Megawatt alternating current

NCA	Nickel Cobalt Aluminium oxide
Nd	Neodymium
NdFeB	Neodymium Iron Boron
NMC/NCM	Lithium nickel manganese cobalt oxide
PE	Polyethylene
PMSG	Permanent magnet synchronous generators
PV	Photovoltaic
R&D	Research and development
REE	Rare earth elements
REO	Rare earth oxide
RES	Renewable energy sources
SETIS	European Commission's Strategic Energy Technologies Information System
Tb	Terbium
tREO	Tonnes of rare earth oxide
TSO	Transmission system operator
US	United States of America
USD	United States Dollar
XLPE	Cross-Linked Polyethylene
yr	year

1 Introduction

1.1 Background

This report provides the results of the detailed assessment on energy technology dependencies, carried out as part of the "Study on energy technology dependence" for the European Commission, DG RTD under Framework Contract PP-02161-2014. The overarching study aims to examine possible 'critical energy technology dependencies' arising from the European transition towards a low-carbon energy sector until 2050 and to recommend specific policy actions that can mitigate such dependencies. The definitions of the concepts 'dependency' and 'critical dependency' as used in this project are given in Box 1-1.

Box 1-1 Definitions of critical dependency

In the context of European energy technology dependence, we define ***dependency*** as:

> *Reliance on an energy technology good, service, component or input that is primarily supplied from outside Europe.*

We further define a ***critical dependency*** as:

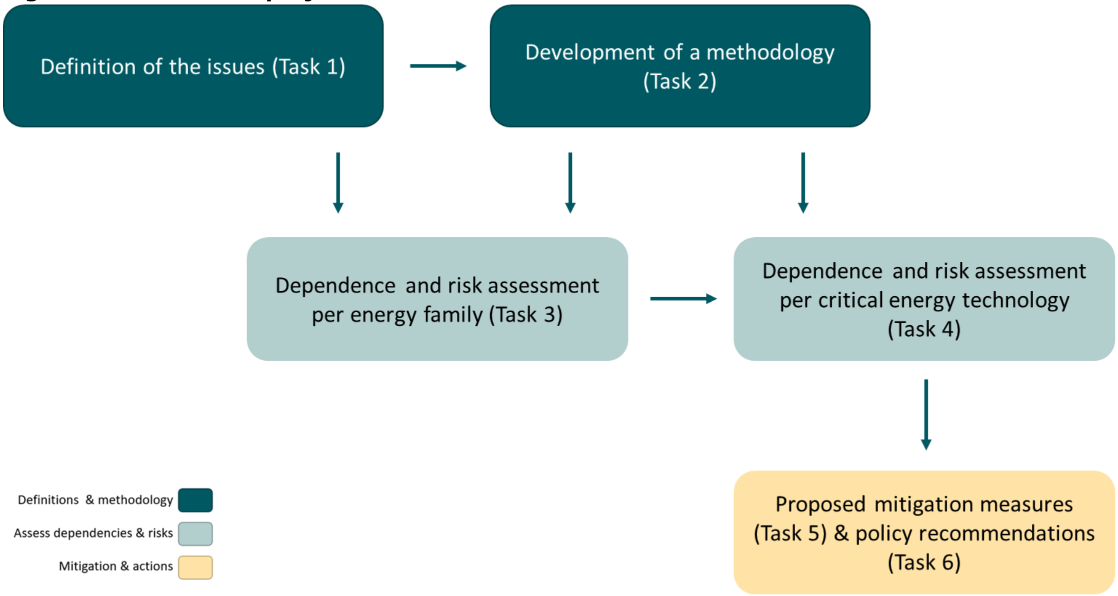
> *Where the extent of the external dependence is assessed as high (>70% reliance on non-EU suppliers) and where the supplier market is concentrated in the hands of few firms or countries (market share of four largest countries or companies >70%), giving them market power and the ability to influence availability and price.*

A critical dependency creates the conditions for potential threats to *European energy technology interests*, defined as:

- Increasing the cost of meeting European climate and energy objectives.
- Reducing productivity and employment in the European energy industry.
- Limiting the potential for European industrial competitiveness.

A schematic overview of the project tasks is provided in Figure 1-1. This report provides the results of the detailed assessment on dependencies (task 4) for three energy technologies: wind energy, solar PV and battery energy storage. These technologies have been selected for a detailed assessment in the preceding project task: the broad brush assessment (task 3). The results of this detailed assessment feed into the development of mitigation measures (Task 5) and policy recommendations (Task 6).

Figure 1-1 Schematic project overview



1.2 Objectives and approach

The detailed assessment for wind energy, solar PV and battery energy storage technologies aimed to:

- validate the critical dependencies identified in the broad brush assessment;
- identify additional critical dependencies; and,
- assess the risks associated with these critical dependencies.

This assessment has been performed through literature review, data analysis and by interviewing industry representatives within the three sectors. Resulting inputs have been used to identify additional dependencies and to assess all identified dependencies based on the following six criteria:

1. **EU external dependence**: measures the percentage of imports compared to total EU consumption and thereby provides an indication of the reliance on supply from outside the EU. Dependencies are only considered critical if the EU relies on non-EU suppliers for a more than 70% of the EU consumption.
2. **Market concentration**: measures the market share of the four largest countries and/or companies to provide an indication of the level of concentration of the supplier market. Dependencies are only considered critical if the EU relies on a limited number of companies or countries for its supply. If the market share of the four largest countries or companies (CR4) is higher than 70%, the market concentration is considered high.
3. **Political risk**: measures the risk of foreign exchange shortages, wars, revolutions, natural disasters and arbitrary government actions in the main supplying countries. High political risk increases the risk of supply disruptions and therefore increases the risk associated with the dependency.
4. **Ease of market entry**: measures the ease with which new companies can enter the market. A higher ease of market entry reduces the risk of dependencies as additional sources of supply can be developed more easily in case of supply disruptions.
5. **Availability of substitutes**: measures the availability of substitutes for the good, service, component or input for which a dependency exists. If appropriate substitutes

are available on the market, it is easier to switch to these substitutes in case of supply disruptions, reducing the risk of the dependency.

6. **Competitiveness trends**: measures the evolution of the competitiveness of the EU industry for the dependency. If the EU industry consistently loses market share, the dependency is expected to become worse, leading to a stronger need for mitigation measures and policy intervention.

A detailed description of the methodology is available in the detailed assessment step-by-step manual delivered as part of this project.

1.3 Reading guide

This report includes the results of the three detailed assessments in separate chapters: wind energy (chapter 2), solar PV (chapter 3), and battery energy storage (chapter 4). Each chapter is structured into the following sections:

1. Introduction: defining the technology, any relevant scope boundaries, and summarising the inputs used for the assessment;
2. Value chain and main dependencies: describing the value chain of the technology and indicating any potential critical dependencies that have been identified;
3. Dependency assessments: separate sections describing the dependency assessment per the criteria mentioned in section 1.2 for each potential critical dependency;
4. Conclusions: summarising the dependency assessment, providing conclusions on the criticality and risk of each dependency and adding further context by summarising the main viewpoints of the industry representatives interviewed for this study.

Annex A provides a list of the industry representatives interviewed for the assessment, Annex B lists the literature used and Annex C contains the step-by-step manual used for conducting the dependency assessments.

2 Detailed assessment: Wind

2.1 Introduction

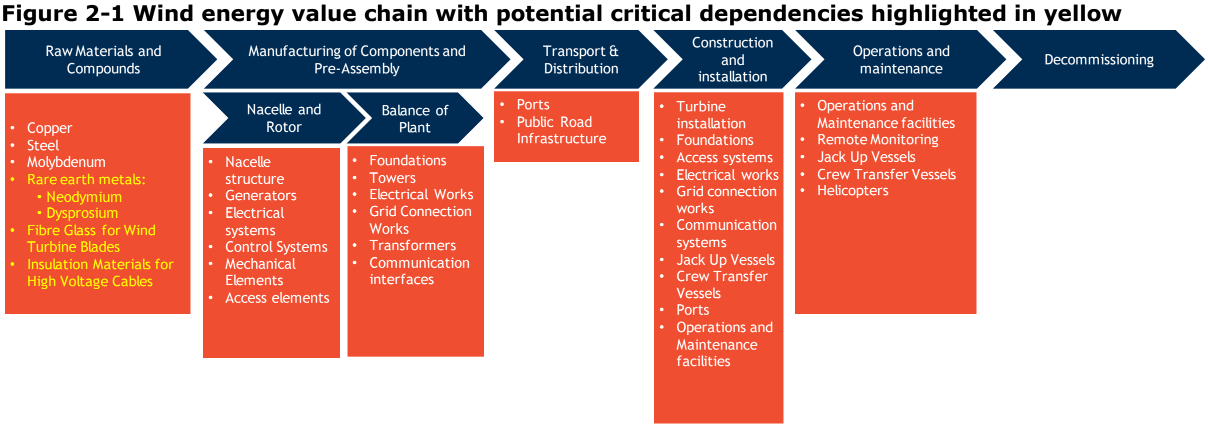
With a total net installed capacity of 168.8 GW in 2016 (153.0 GW onshore and 15.8 GW offshore), wind energy is a major form of power generation capacity in Europe, closely approaching gas-fired power generation capacity (WindEurope, 2017). Europe installed 15.7 GW of new wind power capacity during 2017, a 25% increase compared to 2016. During 2017, 12.6 GW of the installed capacity was onshore and 3.2 GW was offshore.

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.

For this detailed assessment report, the complete value chain of onshore and offshore wind energy technologies has been investigated to identify critical dependencies. As onshore and offshore wind energy share the same critical dependencies, they are assessed together. Where critical dependency elements are of particular relevance for either onshore or offshore wind energy, this is indicated. The findings are based on a series of interviews performed with 11 wind energy experts from companies with headquarters in the EU (see expert list in Annex A) and numerous scientific publications and reports (see Annex B).

2.2 Value chain and main dependencies

Figure 2-1 Wind energy value chain with potential critical dependencies highlighted in yellow



The wind energy value chain can be separated into the following phases:

- **Sourcing of Raw Materials and Compounds** – this phase involves the mining and preparation of the materials and compounds which are necessary for manufacturing the elements of a wind turbine and associated equipment;
- **Manufacturing of Components and Pre-Assembly** – in this phase the main components are manufactured and components are pre-assembled to a state that enables onsite construction and installation. A distinction is made with respect to the Nacelle and Rotor assembly and the Balance of Plant. The Nacelle and Rotor assembly includes all components to convert kinetic energy of the wind to electric

energy. The Balance of Plant includes the support structure, electrical equipment and communications equipment needed for transporting the electrical energy to the grid;

- **Transport and Distribution** – this phase broadly describes the logistical set-up and infrastructure required for the components to be transported to the site of installation;
- **Construction and Installation** – this phase includes all the necessary construction, installation and commissioning works needed for the wind farm to operate and export electricity to the grid;
- **Operations and Maintenance** – this phase describes the products and services required to ensure ongoing operations of the wind farm;
- **Decommissioning** – this phase deals with the necessary activities to remove all elements of the wind farm from the project site at the end of its useful life.

It has been identified in the course of this work stream through the conducted expert interviews that potential dependencies at present are related to (a) the supply of certain raw materials such as two Rare Earth Metals, Neodymium and Dysprosium, (b) the supply of insulation material for High Voltage electrical cables, (c) the supply of fibre glass for wind turbine blades and (d) the supply of Insulated Gate Bipolar Transistor (IGBT). These elements are highlighted in yellow in Figure 2-1 above.

In the following sections, each potential critical dependency (e.g. neodymium and dysprosium) identified above is assessed against the two main critical dependency indicators (i.e. external dependence and market concentration) and additional factors that impact the risk associated with a critical dependence (e.g. country specific risk, market entry barriers, availability of substitutes and competitiveness).

2.3 Neodymium and dysprosium

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:

1. hybrid systems that combine a gearbox with permanent magnets; and
2. direct drive technologies that eliminate the gearbox.

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 (JRC, 2016a). Currently, offshore direct drive models are widely designed with permanent magnets. A key advantage of permanent magnets over alternative technologies is that they reduce turbine size, thereby decreasing overall weight which is important for the offshore wind technology.

Direct drive technology is also being used for onshore wind turbines. This may depend on different parameters such as maintenance advantages, less complicated machinery design, yield efficiency as well as local wind regime and site conditions. Most onshore direct drive low speed wind turbines in the market are also designed with permanent magnets.

Using permanent magnets in both onshore direct drive and offshore technologies increases the demand for the two rare earth metals, Neodymium and Dysprosium (JRC, 2013).

Table 2-1 demonstrates the approximate required permanent magnet amount (in kg per MW) for different types of wind turbines from different manufacturers. Although the reference table is from 2012, the findings are still valid.

Table 2-1 Wind power technologies for large turbines and indication of permanent magnet demand (Jensen, 2012)

Technology	Permanent magnet amount[a]	Generator type and capacity	Manufacturer
Low-speed/direct drive	High	PMSG 6 MW	Siemens Gamesa
Mid-speed/geared	Medium	PMSG 8 MW	Vestas (MHI Vestas)
Low-speed/direct drive	None	EESG[b] 7.58 MW	ENERCON[d]
Low-speed/direct drive	High	PMSG 6 MW	GE
High-speed/geared	None	DFIG[c] 6.2 MW	Senvion
Mid-speed/geared	Medium	PMSG 5 MW	Adven

[a] Typical permanent magnet amount: high=650 kg/MW; medium=160 kg/MW; low=80 kg/MW

[b] EESG - electrically excited synchronous generator

[c] DFIG - doubly-fed induction generator

[d] Over time, ENERCON has upgraded the capacity of its generator

The low-speed direct drive wind turbines mostly require high amounts of permanent magnets. The market share between low-speed, direct-drive permanent magnet synchronous generators (DD-PMSG) and medium and high-speed permanent magnet synchronous generators (MS/HS-PMSG) is approximately equal (JRC, 2013). However, forward looking analysis of the turbine models presented suggests that for the offshore turbine prototypes, DD-PMSG will prevail over MS/HS-PMSG.

Moreover, it is likely that DD-PMSG model’s market share will increase between 2018 and 2020. DD-PMSG types include for example GE's Haliade 150, Siemens SWT-6.0-154 and XEMC-Darwind / Vensys-Goldwind. These models are likely to have a growing market share as can be derived from already signed contracts and pricing strategies by Goldwind. PMSG turbines onshore already have a significant global market share and therefore it is expected that the penetration of PMSG onshore wind turbines will continue**.**

Pavel (Pavel, 2017) shows that 23% of the global installed wind power capacity in 2015 is based on wind turbines using the permanent magnet synchronous generators (PMSG) technology. The remaining 77% are using conventional electromagnet generators based on magnetic steel and copper windings, which have not been identified as critical dependency elements.

Considering the growing installed capacity of wind power and overall benefits of the PMSG wind turbines, the EU demand for neodymium and dysprosium is expected to increase. Table 2-2 shows the estimated annual EU28 demand for neodymium and dysprosium materials. It is noted that the assumptions are based on annual capacity additions in the order of 10-13 GW and that this is estimated to increase (JRC, 2016a).

Table 2-2 Estimations for the annual EU demand of critical rare earth materials for wind energy (JRC, 2013)

Material	Annual EU Demand for Wind Energy (in tons)	
	2020	2030
Neodymium(Nd)-Praseodymium(Pr)*	845	1 222
Dysprosium	58	84

* The report treats neodymium and praseodymium together, as they are not always seperated out (Joint Research Center, 2013, 76).

2.3.1 EU external dependence

The EU wind industry is heavily reliant on China for the rare earths neodymium and dysprosium. Table 2-3 shows EU's dependence on China for these critical raw materials. The EU imports 99% of its dysprosium from China, which makes it fully dependent. Moreover, the EU imports 90% of it is neodymium from China, and the rest comes from Australia, leading to also a full dependency on imports.

Table 2-3 The EU's dependence on Chinese critical raw materials (Rabe, 2017)

Material	Dependency on China	Percentage sourced from China	Other main possible supply sources
Neodymium (Nd)	High	90	Australia
Dysprosium (Dy)	High	99	-

It is also noted that global rare earth elements (REE) demand for the production of all clean energy technologies will reach 51.9 thousand metric tonnes (kt) rare earth oxide (REO) in 2030. Neodymium and Dysprosium comprise 75% and 9% respectively of the projected demand, while these two elements comprise 15% and 0.52% of the global REE resources, respectively.

Figure 2-2 shows a demand calculation for Neodymium Iron Boron (NdFeB) magnets for the 2020 and 2030 NdFeB growth rates scenarios (Schulze, 2016). For the wind generators, very high growth rates are expected for both low and high demand scenarios.

Figure 2-2 NdFeB average annual demand growth rates by application group, years 2020-2030 (Schulze, 2016). The overall demand for NdFeB could increase from low NdFeB demand scenario to high NdFeB demand scenario from between 80–112 kt in 2015 to 240-633kt in 2030 for the low and high NdFeB demand scenario, respectively.

	Average annual demand growth rates for NdFeB demand by application group 2020-30 - low NdFeB demand scenario	Average annual demand growth rates for NdFeB demand by application group 2020-30 - high NdFeB demand scenario
Electric two-wheelers	3%	7%
Air Conditioners	9%	10%
(H)EVs	5%	20%
MRI Scanners	-8%	-2%
Wind Generators	14%	26%
HDDs	-3%	2%
Accoustic transducers	-2%	3%
Separators	1%	4%
Other generators	0%	3%
Other motors	10%	12%
Others	8%	12%

	< -3% (declining)
	-3 to +3% (+/- stable)
	3% to 7% (low growth)
	7% to 10% (high growth)
	>10% (very high growth)

Assuming today's offshore wind technology and its dependency on the rare-earth metals due to required permanent magnet amount for each wind turbine (WindEurope, 2017), an increase of 16% in neodymium and dysprosium demand for EU28 is estimated. The foreseen 26.8 GW onshore and 9.5 GW offshore capacity within EU28 for 2018-2020 period will also require the consumption of the Neodymium and Dysprosium materials continuously as well, taking into account the case that a typical 3 MW wind turbine may contain 360 kg of neodymium and 36 kg of dysprosium in the permanent magnet of the generator (Zhou, 2017). Therefore, today's demand for Neodymium is estimated to be between 2 600 and 2 900 tonnes while the demand for Dysprosium is estimated between of 260 and 290 tonnes.

European energy technology market demand for neodymium may reach 8 000 tonnes/year in 2030, which is about 30% of the current annual global production or about 10% of the projected production of neodymium in 2030. Note that estimated demand for neodymium is for its use in permanent magnets for wind turbines and electrical vehicles – there are no recent separate statistics available for the use of neodymium for each technology. The estimated demand is based on the current observed wind energy capacity additions which should be projected respectively for any considered growth scenarios (in case the manufacturing requirements are to be kept constant).

To conclude, currently, the vast majority of dysprosium and neodymium imported into EU28 is for fabricating permanent magnets in wind turbines. It is expected the demand of these two rare earths in 2030 will be threefold of what it is today.

2.3.2 Market concentration

The current supply market of Neodymium and Dysprosium is heavily concentrated with an estimated 97% of the global supply originating from China (Brumme, 2014). The supply is regulated by the Chinese state and only state-owned companies are legally allowed to mine and trade rare earths (Castilloux, 2018). The Chinese government has imposed a cap on the allowed mining which is, among other things, due to environmental considerations. It is estimated that up to 2013 a large proportion (up to 50%) of the global supply originated from unregulated (or illegal) Chinese mines. However, the Chinese government has been cracking down on these activities since 2013 and thus 'illegal' supply has sharply diminished since then. Notably, an audit recently conducted by Chinese authorities has concluded that a lot of the unregulated supply is in fact over production by licensed companies, therefore closer scrutiny and reporting obligations were imposed on the whole market (Castilloux, 2018).

Neodymium and Dysprosium reserves are not exclusively present in China. These raw materials are present in many other countries. However, mining methods are complicated, labour intensive and create significant pollution, thus further increasing the economic burden on companies operating in jurisdictions with high environmental compliance regulatory requirements and high labour costs. Historically most of the supply originated from US. However since China's market entry in the 1980s, the price dropped due to low labour costs, which drove foreign competing firms out of business. The bottleneck is therefore not one of merely resource availability but rather of economic viability of exploration.

The geographical distribution of Neodymium and Dysprosium is not available; however the broader category of rare earth metals is known to be distributed as per Table 2-4 below

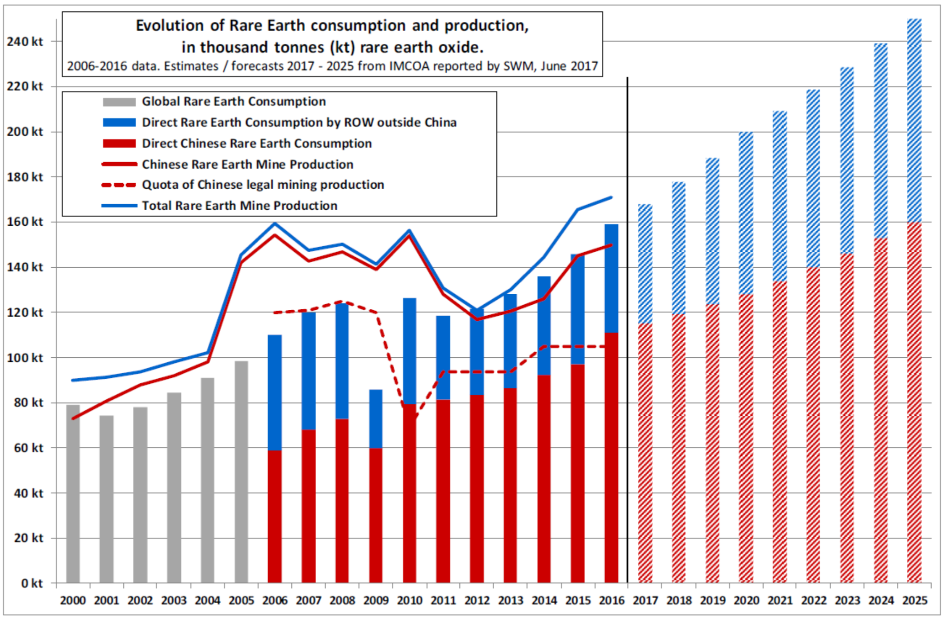
(Brumme, 2014). The figures are reported in tonnes of rare earth oxides (tREO), which are the primary compounds from which rare earth metals are obtained.

Table 2-4 Estimated REO Reserves by Country (Brumme, 2014).

Country Reserves	(tREO)
China	55,000,000
CIS (Commonwealth of Independent States)	19,000,000
USA	13,000,000
India	3,100,000
Australia	1,600,000
Brazil	48,000
Malaysia	30,000
Others	22,000,000
Total	113,778,000

As can be observed from Figure 2-3 below, most of the rare earth oxides production is in China. China accounts for 97% of the mining activities (supply), India (2%), Brazil (0.4%) and Malaysia (0.3%) (Brumme, 2014). Thus, the CR4Country concentration ratio adds up to 99.7%.

Figure 2-3 Evolution of Rare Earth consumption and production, in thousand tonnes (kt) rare earth oxide (Guyonnet, 2018)



Information on the market share of each of the state owned Chinese companies was not found. However, it can be inferred that they are heavily regulated by the Chinese government and that the Chinese government has a big influence on the market structure. Recent reports have indicated that the government has imposed a consolidation on the market, reducing the number of firms extracting rare earths from 90 to 20 to maintain tighter control on overall supply.

2.3.3 Political risk

Considering the dependencies on China and Australia for Dy and Nd; a country specific risk assessment was conducted for these two countries. This assessment is based on the 2017 long-term political risk index (The Global Economy, 2018).

China

Europe relies on China for 99% and 90% of its supply of Dy and Nd, respectively. The long term political risk analysis states a low risk of 2 for China.[1] This is typically acceptable considering the global import and export conditions. The value of 2 has been constant over the period 2014-2017.

On the other hand, the Chinese state has on occasion instructed export quotas on Rare Earth Metals as was the case between September 2010 and January 2015. The quotas were successfully challenged by the US at the World Trade Organization on the basis that it unfairly benefited local Chinese firms who did not face such restrictions. China subsequently dropped the quotas and replaced them with a resource tax (Financial Times, 2015). Considering the critical dependency of these two materials, especially Dy, any other restriction on imports from China could dramatically impact the market in the EU causing big issues for the production of permanent magnets used by turbine manufacturers.

Australia

The same approach for Nd import indicates a long-term political risk index of 1 over 7 for Australia which is the lowest index for political risk related to export transactions. The value of 1 has been constant over the period 2014-2017.

2.3.4 Ease of market entry

As previously mentioned, the recent scientific publications and reports show with no doubt that most of the active mines where the mentioned rare-earth metals are being extracted, later processed or directly imported as oxides are based in China, which makes this country the world leader in mining Nd and Dy. There are also active operations in Russia, US, India, and Australia.

Europe has already explored some of its own potential sources of rare earth elements. For instance, some rare-earth deposits were found in Sweden, Denmark, Finland, Greece and Spain, which suggests that Europe could reduce its reliance on imports of these materials, but the biggest challenge is how to extract and process them in an environmentally and economically sustainable way.

According to the EuRare Project and scientists, Europe has enough rare earth deposits to be self-sufficient in the case that all resources can in fact be mined (EURARE, 2017) (Ahonen, 2015). For this purpose, researchers across Europe and neighbouring countries have been working together to identify deposits and improve mining techniques given that environmental regulations are potentially creating a self-restriction on the supply and may cause long-term delays in the development of mines.

The development process for exploiting a new mine can be summarized in a few steps; starting from obtaining a license, digging the ore, selling the metal, and as soon as the deposit is exhausted, finding another mine location somewhere else. Under these circumstances, constructing a local market with European based local players is still

[1] The political risk index used ranges from 1 (low risk) to 7 (high risk).

considered difficult and it requires time, environmental and nature friendly techniques, efficient application procedures and high investments. On the other hand, opening new mines within EU28 will dramatically lower the dependency on imports from China, consequently a lower market concentration will follow this process in the years of the mining operations. Under these circumstances, ease of market entry is judged to be low and this picture is not expected to change in the short or mid-term.

2.3.5 Availability of substitutes

As mentioned earlier, rare earths used for the production of NdFeB permanent magnets are primarily Nd and Dy. The global proportions of Nd and Dy in NdFeB magnets are on average 20 gr and 5 gr per 100 gr magnet, respectively (Guyonnet, 2018). Considering that these magnets are the most powerful ones in the market today due to their electrical and magnetic properties, it makes the market more dependent and relying on these two materials. On the other hand, as previously mentioned in the above sections; EU demand for these two materials is expected to increase. This means that the dependency on China for Nd and Dy will likely continue for the short to mid-term at least, whereas the turbine manufacturers and permanent magnet producers have been already investigating substitution scenarios for these materials. For example, instead of using around 5% Dy, new types of generators can use permanent magnets with 1% or even less Dy. One of the biggest leading offshore wind turbine manufacturers, Siemens, has a DD-PMSG model which does not require any heavy rare earth elements, in this case Dy or Tb. This model is designed with a larger magnet which requires only more Nd (Guyonnet, 2018).

There has been some research on the direct substitution of Nd with Cerium (Ce) in permanent magnets, but no tangible and applicable results were observed (Pavel, 2017). Terbium (Tb) can be used in place of Dysprosium, but the current price of Tb in the rare-earth minerals market is between 2.5 and 3.0 times higher than that of Dy. Additionally, innovative PMSG designs using ferrite are developed and are expected to reach commercial development in the near future (Green Spur, 2018).

Overall, we conclude that there are substitutes for Dy available, some of them being still work-in-progress. For Nd there are no options for substitution at an acceptable price level at present.

2.3.6 Competitiveness trends

There are at present no commercial Nd and Dy mines in the EU. Hence, an assessment of the competitiveness of this industry could not be performed. What can be said, is that the competitiveness of any new mines in the EU is expected to be low, due the low grade of known deposits (JRC, 2013) and strict environmental regulation.

2.4 Insulation materials for high voltage cables

High voltage cables play a critical role in offshore wind deployment and will play an increasingly important role as the offshore wind industry continues to undergo significant technological developments. For example, wind farms are being installed further from the shore, in deeper waters and with higher unit power requirements. This is expected to increase demand for high voltage cables.

Wind energy market experts from the biggest European based cable manufacturers stated that there are few plastic insulation materials suppliers for high voltage cables. They indicate that there are signs of a monopoly on certain insulation materials, and hence a dependency in the supply chain.

Currently (and in the future), insulation for high voltage onshore and offshore cables is made from XLPE (Cross-Linked Polyethylene). XLPE is a type of thermosetting plastic compound which has different polyethylene (PE) chains linked together ("cross-linking"). This structure helps prevent the polymer from melting or separating at high temperatures (which is an issue with PE). Therefore, XLPE is useful for higher temperature applications. In fact, XLPE may not be pyrolyzed until at 300°C. The common temperature range that such cables face during normal operation is between 90°C and 105°C, while the emergency temperature is around 120°C. In comparison with PE, XLPE has higher dielectric losses, but has better ageing characteristics and resistance to water treeing[2]. Hence, it is highly preferred compared to traditional lapped insulation (paper or paper polypropylene laminate) fluid-filled cables in offshore applications.

In summary, considering the material quality, production process and steady delivery in the market, there may be a critical dependency for high quality XLPE. On the other hand, as offshore wind farm installed capacity and distance from the shore (around 80 – 120 km) increases, direct current (DC) technology will be the required option. Therefore, it is foreseen that this picture will change in the mid or long term due to the developing turbine technologies and the associated new voltage ranges. As a result of this, new designs for the cables will be required. As it has been investigated through recent reports, publications (Case M.8239 – NKT HOLDING A/S / ABB HIGH VOLTAGE CABLE BUSINESS, 2017) and as well as the expert interviews with the biggest European based cable manufacturers and suppliers; XLPE is the commonly used insulation material for the offshore wind cables and it will be also used for the future DC technologies. The insulation market is very dependent on XLPE which plays a critical role within the supply chain.

2.4.1 EU external dependence

XLPE material can be produced by many big and small manufacturers worldwide, but the key points are the quality and the steady delivery for these materials. The quantity of offshore cables required in Europe has increased rapidly as the offshore wind market has grown. Therefore, the amount of XLPE material required for offshore cable insulation has also increased rapidly. The analyses in this section and the following one show that there are only a limited number of suppliers of this material.

Borealis is the biggest XLPE supplier in the world. It has its headquarters in EU28, however, most of the company's shareholders are from outside the EU28 - 64% by Mubadala Investment Company, a sovereign wealth investment company of Abu Dhabi, and 36% by OMV, headquartered in Austria (which is in turn partially owned (~25%) by Mubadala Investment Company). The second biggest supplier, Dow Chemical Company, is headquartered in the US but has significant manufacturing capacities in the EU28. These two companies dominate the XLPE insulation material market in EU28. Overall, there is hardly

[2] Water trees are dendritic patterns which grow in hydrophobic polymers in the presence of AC electric field and water. They can be also called electrochemical trees. Treeing in extruded dielectric cable insulation is the term that has been given to a type of electric deterioration that has the general appearance in a tree-like path through the wall of insulation.

any import of XLPE (mentioned during the interviews) so the EU external dependence is judged to be low.

2.4.2 Market concentration

The market of insulation materials for high voltage cables is a niche market with a complex structure. Readily available statistics do not exist. Therefore, the most appropriate sources of information are market studies on high voltage cable suppliers and expert interviews. The market study which was used for evaluation of the market share of cable manufacturers is the industry update prepared by 4COffshore (4C Offshore, 2018). Since the sales volumes of companies are not available due to confidentiality of the information, we use the distance of cable installed as a proxy for the sales volumes of the companies supplying the insulation materials. It is also important to note that in this chapter the insulation material is aggregated and there is no distinction made for the relative weighting of the various types of insulation materials such as XLPE or EPR, because separate data for each insulation material type is not available.

There are six leading companies supplying insulation material for high voltage cables for offshore wind applications (which is where the insulation material is most crucial), Borealis, Dow Chemical, NKT, Nexans, Prysmian, and Norddeutsche Seekabelwerke GmbH (NSW). As of December 2017, Prysmian has acquired General Cable, the owner of NSW. Cable manufacturers also develop their internal solutions or work with specialist suppliers who develop exclusive compounds for their products.

NKT (including now the high voltage business of ABB), Nexans and Prysmian are known to have a 91% market share of 132 – 220 kV cables manufacturing (4C Offshore, 2018). The combination of the leading companies supplying cable insulation materials would be a mixture between these and Borealis and Dow Chemical. It can be assumed with high certainty that these companies are the suppliers of insulation materials for 91% of the market, however there is no credible way of finding data with respect to who are the leading companies. Anecdotal evidence from the expert interviews hint that Borealis has the largest market share, and Dow Chemical has the second largest market share, however the cable manufacturers also develop internally their own products.

Certain assumptions must be made in order to estimate the market share of the 4 largest suppliers. A weighting approach of the market share is proposed based on information from expert interviews: Borealis = 3A, Dow Chemical = 2A, NKT=A, Nexans=A, Prysmian=A, NSW=A (where A is a normalized value). Based on this weighting it can be inferred that the CR4 Company ≈ 60% (calculated as the result of [6/9]*91%), which should be considered a rough estimate of the market concentration. Similarly, since the above mentioned companies are headquartered either in the EU or the US, the CR4Country Ratio can be estimated to equal at least 91%.

2.4.3 Political risk

The EU28 has a leading position in the manufacturing and supply of high voltage cables and XLPE insulation materials. Although most of the main insulation material suppliers have their own headquarters in Europe, shareholders from United Arab Emirates and the US own the shares of the top two suppliers, above 50% for each individually. This imposes the risk of transfer of manufacturing capacity to non-EU28 countries. Therefore, a long-term political risk analysis was reviewed for each case individually (The Global Economy, 2018). This analysis states the moderate risk of 3 for the United Arab Emirates and 1 for US, scaling from 1 to 7. Combined with the fact that most manufacturers are EU-based, the political risk is judged to be low.

2.4.4 Ease of market entry

Interviews with the market experts indicated that it is not easy to set up XLPE insulation technologies and materials for new market players. However, in recent years, new Asian manufacturers have entered the EU cable market with their own insulation materials.

The start-up capital requirements of manufacturing facilities are high. XLPE production for export cables is a niche market allowing only a limited number of manufacturing companies. The high capital negatively affects the ease of market entry.

The total production cost of XLPE consists of fixed costs for the manufacturing facilities and variable costs for feedstock used in the production process. Fixed costs forms a relatively large part of the total production cost and therefore contribute to a low ease of entrance.

XLPE for high voltage cables is a specialized product that contains several additives to improve the electrical insulation characteristics for this application. It requires extensive research and development activities and intellectual property is unique and protected by patents. In addition, the insulation material is subject to international standards. This contributes to a low ease of entry.

Furthermore, the possibilities for economies of scale are small due to the limited market size of high voltage insulation materials. This, on the other hand, contributes to a high ease of market entry.

Production of XLPE for high voltage cable insulation is a highly specialized process. This requires significant efforts to reach high production and quality standards. This process may require between 3 to 5 years while it also depends on the market demand and steady delivery. This means that there is a challenging learning curve, making it difficult for new market players to enter the market.

Existing big XLPE manufacturers have developed long term relationships with cable manufacturers such as Prysmian, NKT, Nexans and some other non-EU players as well (Case M.8239 – NKT HOLDING A/S / ABB HIGH VOLTAGE CABLE BUSINESS, 2017). Moreover, standing agreements for handling cable failures, quality of the materials, warrantee conditions and maintenance services still impose barriers for new XLPE entrants. This implies that potential new entrants face complex requirements to compete with existing XLPE-suppliers. Recently Chinese cable manufacturers have been able to close cable contracts with a leading TSO in the EU, showing that market entry of XLPE cables from outside EU is possible.

Overall, the high level of capital investment, high level of protected technology, a steep learning curve and tight relationships between suppliers and customers indicate a low ease of market entry for new XLPE-manufacturers for the market of high voltage cables.

2.4.5 Availability of substitutes

Potential substitutes for XLPE insulated high voltage cables are available:

- Ethylene Propylene Rubber (EPR) insulated cables for the shorter term and
- P-laser technology for the longer term.

These two options are assessed separately below.

EPR is already used by some cable manufacturers as a substitute for XLPE offshore high voltage cables. EPR is already used in commercial projects, which means that the Technology Readiness Level is sufficiently high for commercial project applications. Hence, EPR has high potential for adequate substitution of XLPE.

The properties of EPR are not fully equivalent with those of XLPE, showing both benefits and disadvantages for the EPR as substitute material. EPR is more flexible than XLPE, and is therefore easier to handle and install. The material has higher dielectric losses, resulting in a lower efficiency of EPR compared to XLPE. On the other hand, XLPE is weaker to water treeing compared to EPR and requires an impervious metallic lead sheath to avoid direct contact with water. EPR is stronger to water treeing and this gives a satisfactory performance in terms of both electrical reliability and ageing. Therefore, EPR offers a good technical substitute to XLPE insulation material.

The higher dielectric losses of the EPR insulator cause EPR insulated cables to have a lower electrical efficiency. This makes EPR less economical especially for long distance high voltage cables in offshore wind energy projects. In the future, this could change as the performance of EPR material is improved. A change to high voltage direct current (HVDC) for longer cables (in case of remote offshore wind farms) could further improve the competitiveness of EPR applications, since required material properties are more favourable for EPR. Presently, EPR is not the economically preferred option for long distance HV cables but has the potential to act as a substitute in the future.

Apart from the factors mentioned above there doesn't seem to be practical barriers to substituting XLPE for EPR. The current market structure, where there is a strong link between specialized XLPE suppliers and manufacturers of XLPE insulated materials, and the high production standards that are required, contributes to a lower substitution potential for EPR to enter the cable market.

P-laser technology (manufactured by Prysmian), is a candidate for the replacement of XLPE insulated cables in in the longer term. The manufacturing of the cable involves a proprietary thermoplastic technology that is highly recyclable. According to the manufacturer, it has a higher range of operating and emergency temperatures compared to XLPE, between 110 – 130 °C. P-laser technology is potentially a good technical candidate for substitution of XLPE.

It is claimed that production cost could be lower, and that a cost reduction of up to 30% per transmitted MW could be expected. Therefore, also from a commercial perspective, this is a high potential candidate for substitution. At the moment, there is no clear view on practical barriers that exist. Given the high complexity of high voltage cable manufacturing, an extensive road to technical readiness is foreseen. This overview shows that P laser is a serious substitution candidate for the next generation high voltage offshore cables for the wind industry.

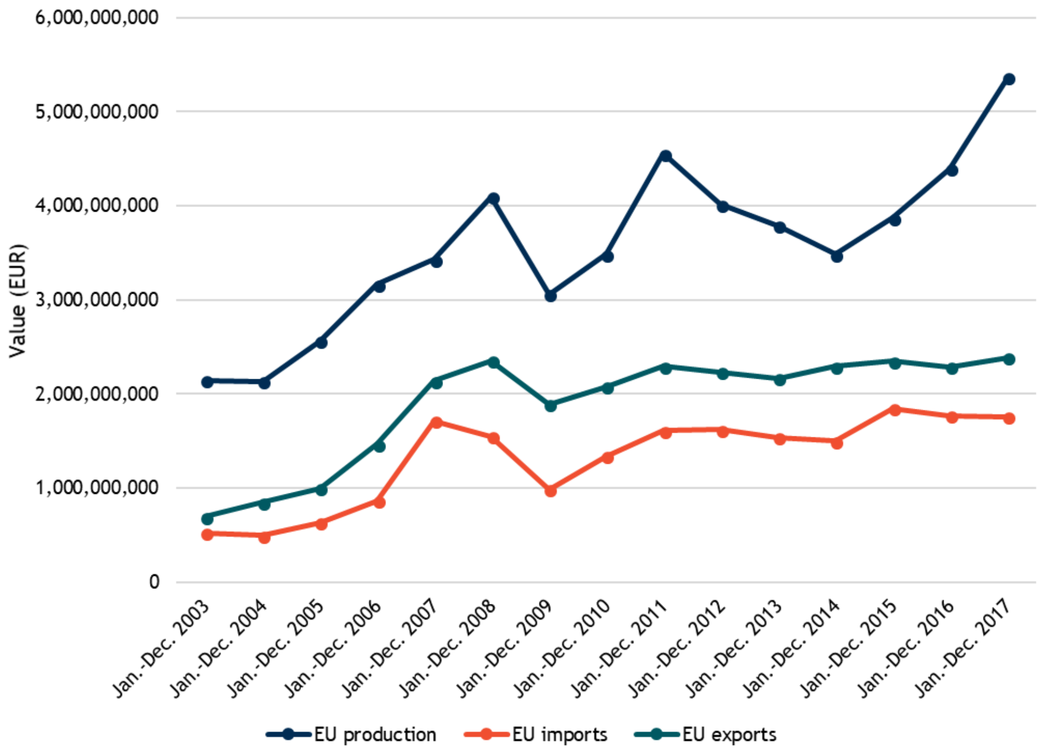
It is concluded that EPR and P-laser technology have a high potential to act as substitute for XLPE insulator material. These materials will be able to decrease the risk of the dependency on the limited number of XLPE suppliers in the market.

2.4.6 Competitiveness trends

As mentioned before, significant production capacity for insulation materials is available in the EU which limits the need to import these materials. This may however change in the case that the EU industry is not able to compete with new market entrants from abroad, such as the new Asian suppliers mentioned before.

For our competitiveness analysis of the EU insulation materials market, we use trade data of the broader category ‘Insulated electric conductors for voltage >1 000 V’ which includes the companies of interest for this analysis. The trade data on this category suggests a strongly increasing production volume in the EU and a relatively stable import and export volume (see Figure 2-4). Based on this data, we conclude that the EU industry has a stable competitiveness outlook.

Figure 2-4 EU production, import and export values -Insulated electric conductors for voltage >1000V



Source: Eurostat - Prodcom. Data extracted on 23 July 2018. Category: 27321400 - Insulated electric conductors for voltage >1 000 V (excluding winding wire, coaxial cable and other coaxial electric conductors, ignition and other wiring sets used in vehicles, aircraft, ships).
Note: Production volume data has data gaps for several years and countries.

2.5 Fibre glass for wind turbine blades

Blades have one of the most important tasks in a wind turbine since they capture the kinetic energy from wind and transfer it to the turbine for producing electricity. As they directly impact the turbine performance, this makes the blades an important component of a turbine. On average, the cost of blades is 20-25% of the total wind turbine cost.

The main differences between onshore and offshore blades are their size and weight. Offshore blades are longer, heavier and built to be more durable to resist stronger winds. On the other hand, in terms of technology, offshore blades are not materially different from onshore blades. The most important indicator to distinguish onshore and offshore blades is the length and consequently the weight. Therefore, for the manufacturers, the main process is the same while they need to adapt their mould and production process.

Fibre glass is used in the manufacturing of wind turbine blades, representing roughly 60% of the raw materials used to produce a blade. It is produced using a combination of extremely thin glass fibres and recovered in two forms such as roving and yarn while yarn is the form that the wind industry mostly uses. Fibre glass is a strong lightweight material. Although, it is not as strong and stiff as composites based on carbon fibre, it is less brittle and its raw materials (such as silica or silicate, with varying amounts of oxides of calcium, magnesium, and boron) are much cheaper. Therefore, it is more efficient in terms of cost of energy production while it also helps to reduce the relative weight of components as turbine sizes increase. Approximately 75% of the wind turbine blades in the EU, and the rest of world, are manufactured from fibre glass composites while the rest is manufactured with carbon fibre spar caps (Composites World, 2018).

Considering the growing installed capacity of EU28 wind power and overall technical and financial benefits of fibre glass blades, the future demand for fibre glass will increase accordingly, and therefore EU's dependency on imports is important to consider.

2.5.1 EU external dependence

The Asia-Pacific region has been dominating the global fibre glass market. China is the biggest manufacturer of fibre glass in the world (European Commission, 2017). As shown in Table 2-5, the market share of imported fibre glass has varied between 34% and 37% between 2012 and 2015, respectively (European Commission (EC 2017)). This is considered a low to moderate dependency. The rest is estimated to be supplied by EU based manufacturers such as Saint – Gobain Vetrotex.

Table 2-5 Fibre glass trade (European Commission, 2017)

Volume of imports by origin (MT)	2012	2013	2014	2015	Average
China	101,953	121,634	148,796	77,669	112,513
Malaysia	60,571	64,188	53,398	68,774	61,733
Egypt	0	0	12,835	45,516	14,588
Norway	33,260	35,255	35,496	41,619	36,408
Turkey	20,940	17,619	19,252	19,703	19,379
Other countries	46,148	47,624	59,493	73,795	56,765
Total Imports	**262,872**	**286,320**	**329,270**	**327,076**	**301,385**
Consumption EU	**750,645**	**813,760**	**897,396**	**960,818**	**855,655**
Imports share of total EU consumption	35%	35%	37%	34%	35%

The mai n reas on that the EU imp orts

from China is the high-quality and low cost of fibre glass produced by the Chinese companies. This is not expected to change rapidly since the overcapacity in China itself is still estimated to be around the total EU fibre glass consumption (European Commission, 2017).

2.5.2 Market concentration

Detailed information with respect to the fibre glass market concentration is difficult to obtain. Information gathered from different sources indicates that in 2014 the global production was in the order of 10 million tonnes (Thomason, 2016). China was responsible for about 2.5 million tonnes. A breakdown of production originating from Chinese companies is provided in Table 2-6.

Table 2-6 Production of Fibre Glass of Leading Chinese Producers

Company	Production ('000 MT)
Jushi Grouo Co. Ltd	1,000
Chongqing Polycomp International Com.	448
Taishan Fiberglass Inc. and Taishan Fibreglass (zoucheng) Co., Ltd.	425
Weibo	170
Shandong Fiberglass Composite Materials Co .. Ltd.	180
Jiangsu Changhai Composite Materials Co. Ltd.	100
Changzhou tianma group Co. Ltd	30
PPG Sinoma Jingjing Fiber Glass Co. Ltd.	60
Xingtai JinNiu Fiber Glass Co., Ltd.	60
Jiangsu Jiuding New Material Co Ltd	70
Total	**2,543**

Thus, it can be inferred that the market share of Chinese companies is about 25%. In respect of the CR4Country metric, from the data provided in Table 2-6 above it can be inferred that the average CR4Country ratio between 2012 and 2015 is approximately 87% (see Table 2-7 below).

Table 2-7 CR4 country estimation for fibre glass dependency

Volume of imports by origin (MT)	2012	2013	2014	2015	Average
EU	487,773	527,440	568,126	633,742	554,270
China	101,953	121,634	148,796	77,669	112,513
Malaysia	60,571	64,188	53,398	68,774	61,733
Egypt	0	0	12,835	45,516	14,588
Consumption EU	**750,645**	**813,760**	**897,396**	**960,818**	**855,655**
CR4 Country	**87%**	**88%**	**87%**	**86%**	**87%**

2.5.3 Political risk

Considering the EU depends mostly on China, Malaysia, Norway, Egypt, and then US, Japan and India respectively for the fibre glass imports; a country specific risk assessment was conducted for these countries. This assessment is based on the 2017 long-term political risk index (The Global Economy, 2018).

<u>China</u>

EU relies on China for around 40% of its fibre glass supply. The long term political risk analysis states a low risk of 2 for China. This is typically acceptable considering the global import and export conditions. The value of 2 has been constant over the period 2014-2017.

Malaysia

The long term political risk analysis states a moderate risk of 3 for Malaysia and this country is the second biggest fibre glass supplier to the EU28. Therefore, it may still be relevant to conduct a further analysis on trade sustainability and mitigation strategies for the mid-term. The value of 3 has been constant over the period 2015-2017.

Norway

The same approach for fibre glass import indicates a long-term political risk index of 1 over 7 for Norway which is the lowest index for political risk related to export transactions. The value of 1 has been constant over the period 2014-2017.

Egypt

Although the long term political risk analysis states a high risk of 6 for Egypt, the low import volume from this country is not expected to impact the market significantly. The value of 6 has been constant over the period 2014-2017.

US and Japan

The same approach for fibre glass import indicates a long-term political risk index of 1 over 7 for US and Japan which is the lowest index for political risk related to export transactions. The value of 1 has been constant over the period 2014-2017.

India

Although the long term political risk analysis states a moderate risk of 3 for India, the low import volume from this country is not expected to impact the market significantly. The value of 3 has been constant over the period 2014-2017.

2.5.4 Ease of market entry

Bigger wind turbine models require longer blades, so the weight and materials of the blades are key parameters for the structure of the components. Fibre glass blades are one of the most expensive components of a wind turbine, therefore blade manufacturers have been investing in current and future technologies continuously to optimize their fixed costs and strategic position within the market. Entering the market for a new manufacturer requires unique designs and manufacturing processes which in turn require significant R&D activities. Moreover, this process is subject to a number of international standards, technological qualifications, safety and experience; therefore, the importance of learning effects is considered strong. This results in a low ease of market entry.

As mentioned in the previous sections, currently, fibre glass is still a commonly used material for onshore and also offshore blades manufactured in EU28. As the local market in EU28 is dramatically impacted by the low-cost supply strategies and imports of fibre glass from Chinese and other Asian companies; EU28 companies have not been able to compete with pricing strategies of these suppliers. Therefore, this also indicates a low ease of market entry.

On the other hand, several EU28 based global blade manufacturers are already supplying fibre glass blades sufficiently within the EU. LM Wind Power is one of the biggest EU28 based blade manufacturers and despite being a part of GE, it still has independent long-term agreements with several global turbine manufacturers relying on required protocols and confidentiality. Additionally, although the biggest EU28 based turbine manufacturers - such as Vestas, Siemens Gamesa, ENERCON, Nordex, etc - have their blade manufacturing facilities worldwide and they produce both fibre glass and carbon fibre blades, the manufacturers are still quite conservative with their intellectual properties (IP). This statement was also confirmed during interviewees with two turbine manufacturers. Therefore, local production in different countries or regions worldwide is already available but independent from IP considerations.

In summary, there is still a significant barrier observed for the potential market players where it might be difficult to develop their own technologies with cost-effective research and development activities, high start-up capital requirements for manufacturing facilities and long-term relationships with the buyers.

2.5.5 Availability of substitutes

The biggest blade and wind turbine manufacturers in the world are based in EU28: Vestas, Siemens Gamesa, GE, ENERCON, Nordex/Acciona, Senvion and LM Wind Power. These companies are capable of manufacturing both fibre glass and carbon fibre blades. In the event of a fibre glass shortage, carbon fibres can act as a substitute, also depending on the selected onshore or offshore blade technology and the wind turbine model.

Higher performance wind turbines require longer blades. Today, onshore turbines reach up to 4 MW, while offshore turbines are being installed between 6 to 9 MW with blade lengths between 65 and 88 m. Recently, GE Renewable Energy announced their new 12 GW offshore turbine model with 107 m long blades.

Such large sized wind turbine blades require relatively light materials to compensate for the difference of the bigger and therefore heavier structure of the wind turbine (Mishnaevsky, 2017). Although fibre glass reinforced blades are currently used mostly in the market, the biggest EU based turbine manufacturers, Vestas and Siemens Gamesa RE, have already been investing in new solutions. For example, carbon fibres are already replacing fibre glass due to their rigidity and light weight properties (Mishnaevsky, 2017). For example, the Siemens 6 MW wind turbine has a weight per megawatt similar to that of many turbines in the 2 to 3 MW range in the market. Figure 2-5 shows the evolution of fibre glass and carbon fibre blades for different weights and blade lengths while Figure 2-6 shows the rotor diameter evolution as a function of time in Europe.

Figure 2-5 Blade weight relationship with length (Source: BNEF and JRC, offshore wind turbines database)

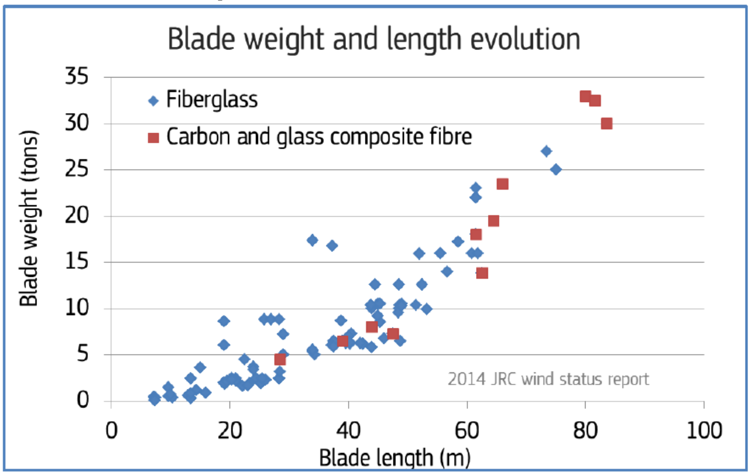
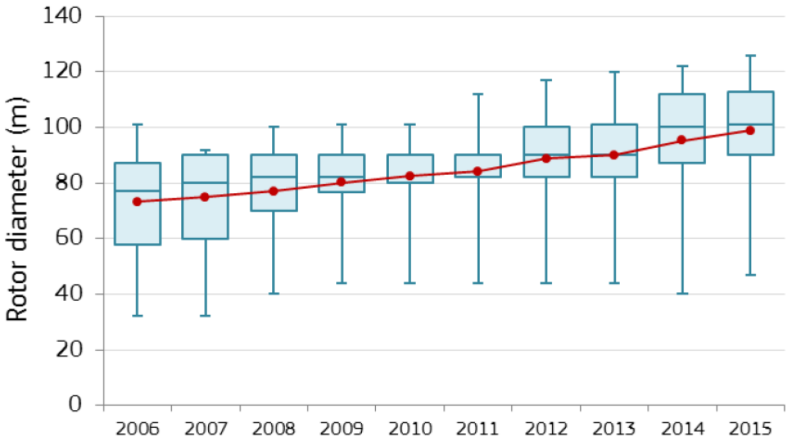


Figure 2-6 Onshore Rotor diameter evolution in Europe (JRC, 2016a)



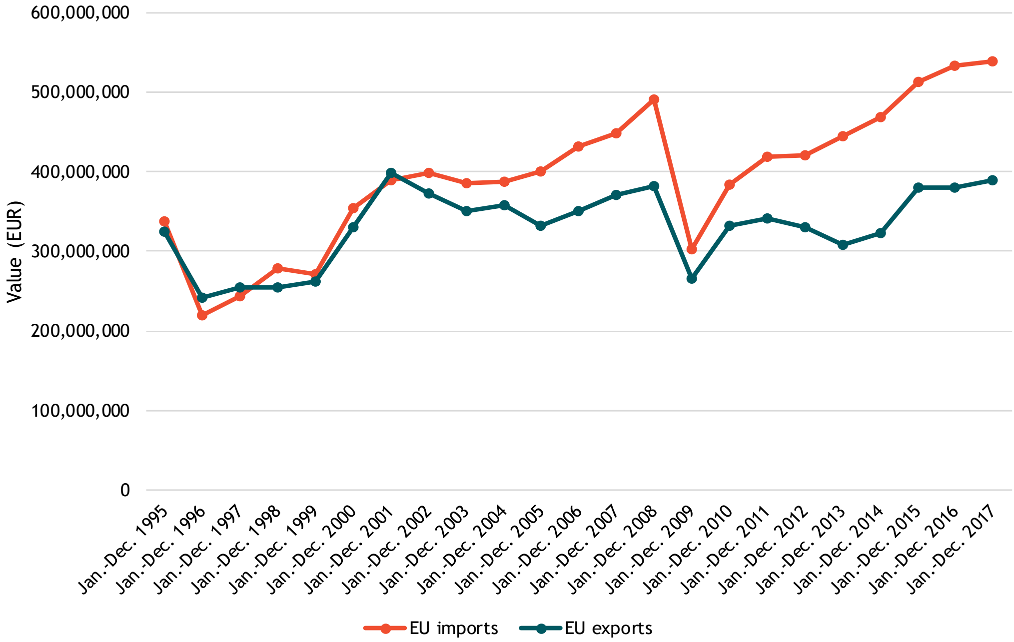
Both figures together indicate that the wind turbine blades are getting longer with new developed technologies and designs. In addition to these figures, several wind turbine models from different manufacturers with rotor diameters between 130 – 180 m are already in commercial operation (4C Offshore, 2018). Therefore, in the evolution to longer blades, which is already the case in the global market, carbon fibre will most likely be used to substitute fibre glass in the production of future turbine blades. On the other hand, although carbon is lighter and stronger, it is almost two-three times more expensive and is also more difficult to produce. Hence, for the mid-term, fibre glass is expected to remain an important material for turbine blades.

In summary, as the blades get bigger and longer, to compensate the increasing weight, therefore the mechanical loads; fibre glass is expected to be replaced with carbon fibre for the offshore wind turbines. Depending on the selected cost-effective technology and the site conditions; bigger onshore wind turbine blades will also require lighter elements to eliminate the additional material weight, where carbon fibre can be a stable and substitute material.

2.5.6 Competitiveness trends

Trade in fibre glass is reported under the category 'Glass fibre filaments (including rovings)' in Eurostat - Prodcom.[3] The import and export values shown in Figure 2-7 show that the EU is a net importer and that the trade deficit has increased over the past decade. Hence, there is a risk that the import dependency on fibre glass will increase over time and as a result, the criticality of this dependency will increase.

Figure 2-7 EU import and export values - Glass fibre filaments (including rovings)



Source: Eurostat - Prodcom. Data extracted on 27 July 2018. Category: 23141130 - Glass fibre filaments (including rovings)

2.6 Insulated gate bipolar transistors (IGBTs)

In addition to gear boxes, generators and blades, wind turbines consist of high-tech electronics background to ensure that the turbine performs as efficiently and steadily as possible. An analysis conducted by Wind Energy Update shows that 50% of all failures in wind turbines are due to problems in electronics or electrical structure (New Energy Update, 2011). This is a significant percentage and requires the same attention as the gear boxes, generators or blades.

An expert interviewed for this study pointed out that Insulated Gate Bipolar Transistors (IGBT) have an important role with their electronical features in turbine electronics. An IGBT is a large power transistor and decreases the thermal resistance between the IGBT driver and its heat sink. IGBTs are power switching devices which combine the advantages of the Bipolar Junction Transistor (BJT) and Metal Oxide Semiconductor Field Effect Transistor (MOSFET). The BJTs are capable of providing superior current density while the MOSFETs can be controlled by voltage (Busca, et al., 2011). Therefore, IGBTs are a combination of these two transistors and they merge these two advantages of having high current density and being voltage driven. It has lower on-state resistance, conduction losses and ability to switch

[3] https://ec.europa.eu/eurostat/web/prodcom/data/database

high voltages at high frequencies without damage. These features make the IGBT ideal for driving inductive loads such as electromagnets and DC motors.

IGBTs play a key role for almost all types of onshore and offshore wind turbines and it is one of the power semiconductors that is used for the power conversion and for coupling the generator with the grid.

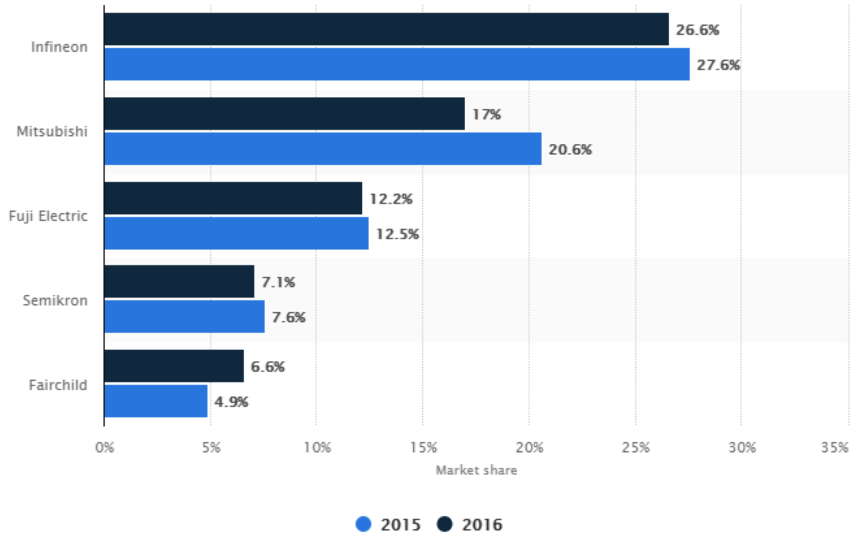
2.6.1 EU external dependence

There is no data on the imports and exports of IGBTs, thereby not allowing for a quantitative assessment of the EU external dependence on IGBTs. The data available on market concentration (see next section) and import/export volumes for the broader category of semiconductor diodes (see competitiveness trends section), does provide sufficient information to draw a conclusion on the EU external dependence on IGBTs. First, market concentration analysis shows that 2 out of the top 5 suppliers of IGBTs are EU-based, together accounting for a global market share over 30%. The import/export analysis of semiconductor diodes further shows that imports and exports are at a similar level. Taking these findings into account, we estimate that the EU has a low reliance on external supply, if any.

2.6.2 Market concentration

The global market share of companies supplying IGBT products is shown in Figure 2-8 below.

Figure 2-8 Manufacturers' share of insulated-gate bipolar transistor (IGBT) based power semiconductor market in 2015 and 2016 (Source: https://www.statista.com/statistics/653187/worldwide-igbt-based-power-semiconductor-market-share-by-vendor/)



Based on the above it can be inferred that the CR4 Company ratio is 62.9%. There isn't sufficient data available to make an accurate estimation of the CR4 Country Ratio, since the manufacturers shown in Figure 2-8 above comprise about 70% of the market and other data to estimate the market share of the suppliers comprising the rest of the market is not available. However, based on data shown in Figure 2-8 above, it can be extrapolated with a medium degree of certainty that the C4Country ratio would be at least 69.5% as the leading suppliers are headquartered as follows: Infineon - Austria (EU), Mitsubishi – Japan, Fuji Electric - Japan, Semikron – Germany (EU), and Fairchild – US.

2.6.3 Ease of market entry

Experts indicate that the IGBT manufacturing process is highly automated and reliant on capital investments and process engineering expertise, leading to relatively high barriers of entry for this market. It should also be noted that the companies supplying IGBT related products are in general diversified industrial players who benefit from scale and supply chain efficiencies. Therefore, we estimate that the ease of market entry is low for the IGBT market.

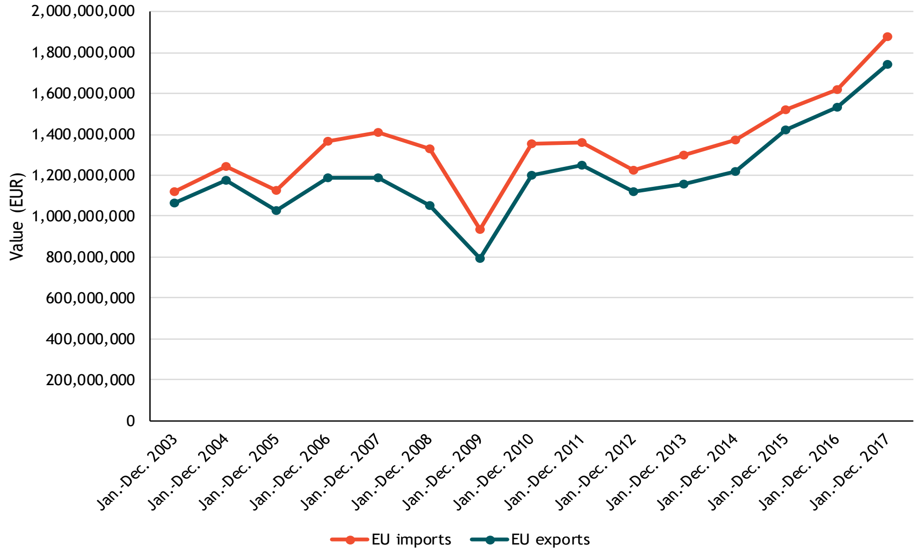
2.6.4 Political risk

As the biggest IGBT manufacturers such as Infineon (Germany) and ABB Semiconductors (Switzerland) are located with their headquarters in Europe and due to sufficient local supplies from these companies, political risk is assessed to be low.

2.6.5 Competitiveness trends

Trade in IGBTs is reported under the category 'Semiconductor diodes', which is broader than IGBTs only. Hence, these figures cannot be treated as a fully accurate estimate of the trade in IGBTs but do provide an indication on the competitiveness of the EU IGBT industry. Figure 2-9 shows that the EU import and export values for this category of products are at a comparable level, with a slight trade deficit. The trade deficit remained fairly stable over the past years. Hence, we conclude that the competitiveness of the EU IGBT industry is stable.

Figure 2-9 EU import and export values - Semiconductor diodes



Source: Eurostat - Prodcom. Data extracted on 27 July 2018. Category: 26112120 - Semiconductor diodes

2.7 Conclusions

2.7.1 Assessment of dependencies

Table 2-8 summarizes the analysis of the dependencies for wind energy.

Table 2-8 Summary of detailed assessment on dependencies for wind energy

Dependency	Import share	Market concentration (CR4)	Political risk	Ease of market entry	Availability of substitutes	Competitiveness trends
Neodymium	>99%	99%[4]	Low	Low	No/limited	Not applicable
Dysprosium	>99%	99%[5]	Low	Low	Yes - in progress	Not applicable
HVDC insulation materials	Low	91%	Low	Medium	Yes - in progress	Stable
Fibre glass	>35%	87%[6]	Low	Medium	Yes - available	Declining
IGBTs	Low	70%	Low	High	No/limited	Stable

The main conclusions that can be drawn from this analysis are:

Neodymium and dysprosium are the main critical dependencies in the wind energy sector

The detailed analysis of wind energy dependencies in this report confirms the criticality of the dependencies for neodymium and dysprosium that were suggested in the broad brush assessment conducted as part of this study. For both materials the EU is fully reliant on non-EU suppliers which are heavily concentrated in a few countries. The risk is somewhat alleviated by the low political risk associated with the main supplying countries. However, the difficulties to enter the market for new suppliers and the lack of suitable substitutes, in particular for neodymium, result in a high risk of these dependencies overall. This holds even more as China is in both cases by far the dominant supplier. Whereas the political assessment for this country gives an overall low political risk, past market conflicts regarding solar PV (with the EU) and rare earth metals (with Japan) suggest that mitigation measures for these two raw materials might be warranted.

For fibre glass, present dependencies give some reason for concern, but no urgent need for action

For fibre glass the dependency risk is somewhat higher due to the higher import share and the declining competitive position of the EU industry. 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.

HVDC insulation materials and IGBTs are not considered critical dependencies

The dependency on HVDC insulation material suppliers that was suggested by some of the interviewees is not considered a critical dependency per the criteria used in this study. This is mainly because HVDC insulation materials are primarily supplied from EU-based factories. 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. But considering the stable competitiveness of the EU industry, there is little reason for concern at this moment.

---

[4] CR4 country
[5] CR4 country
[6] CR4 country

Neither is the suggested dependency for IGBTs confirmed by our analysis. The main reason is 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.

2.7.2 Industry perspective on dependencies

The outcomes of this independent assessment of technology dependencies for wind power can be held against the viewpoints of industry on dependencies, which emerged during the interviews held in this study. The main viewpoints of the industry are:

Critical dependencies are not considered a major risk for the EU wind energy industry

Overall, the industry representatives interviewed for this study are not particularly concerned about dependencies in the wind energy supply chain. The EU has a strong position in most parts of the supply chain and the manufacturers at different stages of the supply chain have sufficient options to choose from. Moreover, certain elements of wind turbines can be recycled and substitutes are available. The industry is slightly concerned about the risk of trade disputes with China and a potential decline in the competitiveness of the EU wind turbine manufacturers. Looking at the recent import and export volumes of the sector (see Figure 2-10), there may indeed be reason for concern as exports have decreased considerably over the past two years. While this may be partly due to other reasons such as decreasing wind turbine prices[7] and an increase in domestic demand (EU capacity additions were at a record level in 2017, 12% higher than in 2016[8]), a continuation of this trend would be reason for concern. But overall, the wind energy industry does not see severe risks due to critical dependencies.

Figure 2-10 Production, import and export values – Generating sets, wind powered

[7] As the analysis is based on import and export values, a decrease in unit price would lead to reduced values even when volumes remain the same.

[8] Own elaboration based on data from IRENA INSPIRE.

Source: Eurostat - Prodcom. Data extracted on 23 July 2018. Category: 28112400 - Generating sets, wind-powered

Policy instability is the main risk for the wind energy industry

The main concern of the wind energy industry is policy instability and the impact that changes in policy can have on the demand for wind turbines. Both a decline or a sudden increase in capacity additions would lead to severe issues for the sector. Long term policy goals on capacity additions such as the EU's 20-20-20 targets are therefore appreciated by the industry.

3 Detailed assessment: Solar PV

3.1 Introduction

There are a variety of different solar photovoltaic (PV) technologies, which are commonly differentiated by the semi-conducting materials used for the modules. Two sub-groups can be identified:

- crystalline silicon (c-Si) both in the form of mono or poly crystalline silicon, 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.

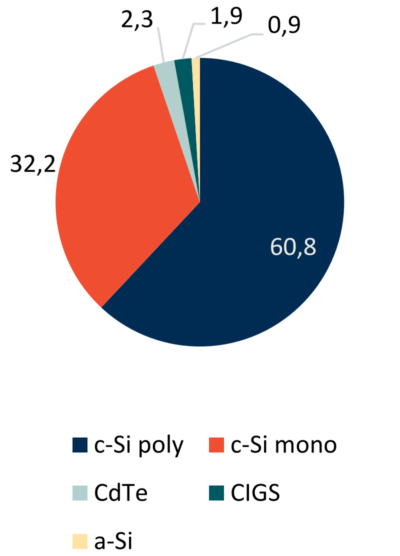


Figure 3-1 Percentage of 2017 global annual production per PV technology (Fraunhofer ISE, 2018)

As shown in Figure 3-1, 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). Since crystalline silicon technologies represent 95% of the global annual production of PV technologies, only this technology was selected for a detailed analysis.

For this detailed assessment report, the complete value chain of crystalline silicon PV technology and balance-of-system components[9] has been investigated. The findings are based on a series of interviews performed with 10 solar energy experts (see expert list in annex A), scientific publications and reports (see Annex B: References).

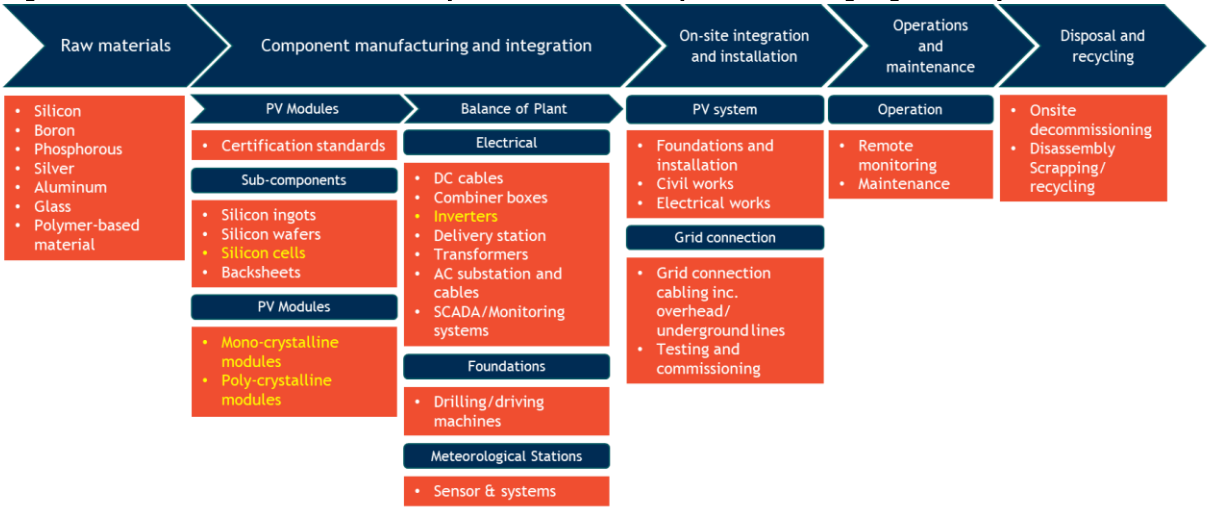
3.2 Value chain and main dependencies

The value chain for solar PV consists of the key components required for a functioning PV system, such as PV modules and balance-of-plant components (e.g. cables, inverters, transformers, monitoring equipment, etc.), the raw materials needed for their manufacturing, and services and ancillary products required for the installation, operation, maintenance and decommissioning of PV plants.

Figure 3-2 presents an overview of the PV value chain, and indicates the main critical dependencies identified for these technologies (in yellow).

[9] All materials involved excluding the PV modules, including the cables, inverters, transformers, mounting structure, monitoring equipment, etc.

Figure 3-2 Solar PV value chain with potential critical dependencies highlighted in yellow



Source: own elaboration.

The break-down proposed in Figure 3-2 was constructed to highlight the proliferation of vertically-integrated module manufacturers who are able to produce all sub-components required for the production of modules. The value chain for solar PV includes the following steps:

- **Raw materials** extraction/production for the manufacturing of crystalline silicon modules includes materials for the manufacturing of PV cells (consisting mainly of silicon, but also other elements for polarity and for the development of the anti-reflective coating), materials for manufacturing protective encapsulation, glass cover and backsheet, and materials for the metal frame (European Commission, 2017) (Mathieux, et al., 2017);
- **Component manufacturing and integration** includes both the sub-components related to the manufacturing phases of PV modules (silicon ingots, wafers, cells), and the manufacturing of balance-of-plant components (from DC cables connecting individual modules up to the point of connection to the electrical grid or to the point of consumption in case of off-grid application). This category of components is quite diverse and varied across PV applications. However, some key components can be found in all PV plants for example inverters and DC combiner boxes;
- **On-site construction, assembly and installation** includes all services related to project development, construction, and testing, up to the point where the plant is able to produce electricity;
- **Operation and maintenance** includes the products (components mentioned above and other products) and services required to ensure the ongoing operations of the power plant;
- **Disposal and recycling** includes the necessary activities needed to remove all the elements of the power plant from the project site, and the established industry of PV modules recycling (which is however not common to all plants).

The results of the analysis indicate that potential critical dependencies mainly relate to the production of PV cells, modules and inverters. The fabrication of PV cells and modules is predominantly performed in Asian countries (China in particular) as the EU cell manufacturers have not been able to match the declining prices of Asian competitors and have almost entirely left the business (IEA PVPS, 2018). Regarding electrical power inverters (DC to AC inverters), out of the top five solar inverter companies, responsible for over 50% of the global annual production (REN21, 2017), two have headquarters in the EU (SMA Solar in Germany and ABB in Switzerland), although production is not restricted to EU countries. Experts have noted that the inverter market is dominated by large companies (GTMResearch inverter concentration, 2016), which could increase EU external dependency if the non-EU manufacturers are more successful in the market consolidation.

3.3 PV cells and modules

PV modules produce direct current (DC) by converting sunlight to electrical energy. Combined with inverters, modules form the basis of PV systems. A crystalline silicon (c-Si) module is typically composed of 60 or 72 interconnected cells. The cells generate power, whereas other components provide structure and durability (e.g. glass, encapsulant, frame), conductivity (wires) and safety (bypass diodes). The value of the cells is also reflected in the costs, which account for more than half of the module price (GTM Research, 2015).

Cells and modules are often manufactured by the same company. Once the cells are produced, assembling them into modules is a straight-forward process. In regional markets, module production capacity is reflected in cell production capacity, and vice-versa. As a result, dependencies on cell and module manufacturing capacity are also highly related. Therefore, we analyse these dependencies together and indicate differences between cell and module manufacturing where relevant.

3.3.1 EU external dependence

Net import of modules into the EU is derived from the difference between apparent consumption (annual installed capacity in the EU) and EU module production. The apparent consumption is equal to the annual installed capacity for a given year. Table 3-1 lists EU and global installed capacities for 2017 as reported by various sources. The far right column shows the EU share of the total capacity installed globally. Fraunhofer ISE reports a considerably higher installed capacity for EU countries than other sources. Although not specifically mentioned, this figure likely includes installations in European countries that are not part of the EU-28. Non-EU-28 countries (including Turkey) accounted for 2.5 GW in newly installed capacity in Europe in 2017 (SolarPower Europe, 2018).

Table 3-1 EU/ Europa share of global solar PV capacity additions (Fraunhofer ISE, 2018; SolarPower Europe, 2018; IRENA, 2018)

Source	2017 capacity additions EU/Europe (GW)	2017 capacity additions global (GW)	EU/Europe share of global capacity additions (%)
Fraunhofer ISE (Europe)	8.6	94.6	9.1
SolarPower Europe (EU-28)	6	98.9	6.1
IRENA (EU-28)	5.3	92.5	5.7

European module production is estimated to be approximately 2 GW (JRC, 2018b) which is at most 1.8% of the global production capacity (global production is 110 GW (JRC, 2018a), production capacity is probably somewhat higher). The difference between this figure and the apparent consumption yields the EU external dependence[10] (see Table 3-2).

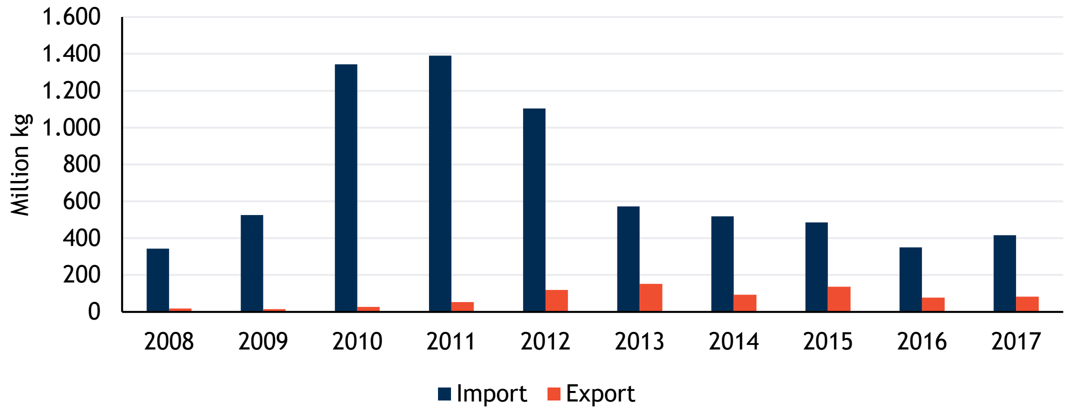
Table 3-2 EU external dependence indicators, in 2017 (Fraunhofer ISE, 2018; SolarPower Europe, 2018; IRENA, 2018)

Source	EU Share of global capacity additions (%)	EU share of global production (%)	EU external dependence indicator
Fraunhofer ISE (Europe)	9.1	1.8	0.80
SolarPower Europe (EU-28)	6.1	1.8	0.71
IRENA (EU-28)	5.7	1.8	0.68

Note that the external dependence indicators are based on European production capacity. This includes contributions from non-EU countries. Assuming that module production is not limited to EU member countries, the actual EU external dependence will be larger than reported (except for the Fraunhofer estimate which also covers Europe for capacity additions instead of EU-28). This estimation is therefore considered moderately accurate.

Trade statistics from the EC Market Access Database support the notion of a large net import for PV technology into the EU. Figure 3-3 shows the trade volumes for photovoltaic devices (excluding LEDs) in the EU over the last decade. Across the entire time-series, a sizeable gap between import and export is observed.

Figure 3-3 Import and export of photovoltaic devices into the EU from 2008-2017 (European Commission, 2017)



EU external dependence on PV cells & modules is also expected to increase in the near future due to growth of the European PV market. Analysts predict 30% growth in net annual capacity additions for 2018, which will then gradually fall off in the following years. By 2021, annual EU additions should surpass 15 GW (T-Solar, 2017). Meanwhile, there are no signs of large capacity expansions for PV module manufacturers in Europe. Therefore, suppliers in the EU will have to increase imports to meet demand.

Based on the indicators listed in Table 3-2, we conclude that the EU external dependence for PV modules is between 65 and 80%[11]. An estimation of the import shares for PV cells was

[10] Calculated as: External dependence indicator = (Share of total production Europe - Share of total capacity EU) / Share of total capacity EU.

provided by the interviewees and reviewers. Based on their insights, we conclude that the EU external dependence for cells is higher, at more than 90%.

3.3.2 Market concentration

The market for PV modules and cells is heavily concentrated around China. In 2017, the list of top-10 companies in terms of module shipments (combined controlling 56% of the shipments) include seven firms from China, one from Korea (Hanwha Q-Cells), one from Canada (Canadian Solar)[12], and one from the USA (First Solar) (GlobalData, 2017). Table 3-3 lists the four-firm concentration ratio (CR4) based on market shares of shipped nameplate capacity. Between the top-10 companies, shipments ranged from ca. 2.5 GW (Risen Energy) to just under 10 GW (Jinko Solar). Company rankings may vary across different sources as shipment data is not always shared publicly (PV-Tech, 2018).

Table 3-3 Company market shares of PV module shipments in 2017 (GlobalData, 2017)

Company	Shipments (GW)	Market share (%)
Jinko Solar	9.70	9.86
Trina Solar	9.10	9.25
JA Solar	7.50	7.62
Canadian Solar	6.85	6.96
CR4 Firm	**33,15**	**33,69**

The landscape of large scale PV cell manufacturers is very similar to the module supplier market. Top producers of c-Si PV cells include Hanwha Q-cells, JA Solar, Jinko Solar and Trina Solar. As previously stated, vertical integration of cell and module production is common among PV manufacturers. Yet, this mainly holds true for the largest companies in the industry. In fact, the global market for cell production is reasonably distributed, more so than the module market. In 2016, for PV modules, the market share of the top-10 suppliers is about 60 % (PV-Tech, 2018) while the cumulative shipments of the top-10 cell manufacturers accounted for less than 40 % of the total shipped capacity (PV-Tech, 2017).

In 2013, the EU introduced an import tariff for Chinese PV cells and modules. The trade regulations were revised for 2016 to include EU imports from Chinese firms in Taiwan and Malaysia. As a result of this dispute, Chinese companies have been moving their production lines to other parts of the Asia-Pacific region. For example, Vietnam has seen capacity expansions from the likes of Jinko Solar, Trina Solar and JA Solar (Taiyang News, 2017). Figure 3-4 depicts the import shares of the ten largest countries in terms of shipments of photovoltaic devices into the EU. It illustrates the effect of the trade restrictions on Chinese PV technology, including EU imports via Taiwan and Malaysia. Recently the tariffs were completely removed, which could lead to a change in the future market (European Commission, 2018).

[11] This large range is caused by inconsistencies and inaccurate definitions on the input data, in particular concerning the geographical scope: EU28 or Europe. As not all data was available for EU28 only, some European estimates were used which led to different estimates of the external dependence.
[12] in view of this assessment note that Canadian Solar runs the bulk of its production facilities from China and may be a Chinese private company soon as the Chinese CEO of Canadian Solar is in the process of buying all shares of the company (PV Magazine, 2017). The company is therefore commonly labelled as a Chinese manufacturer.

Figure 3-4 Import shares of photovoltaic devices into the EU-28 by country, from 2008-2017 (European Commission, 2017)

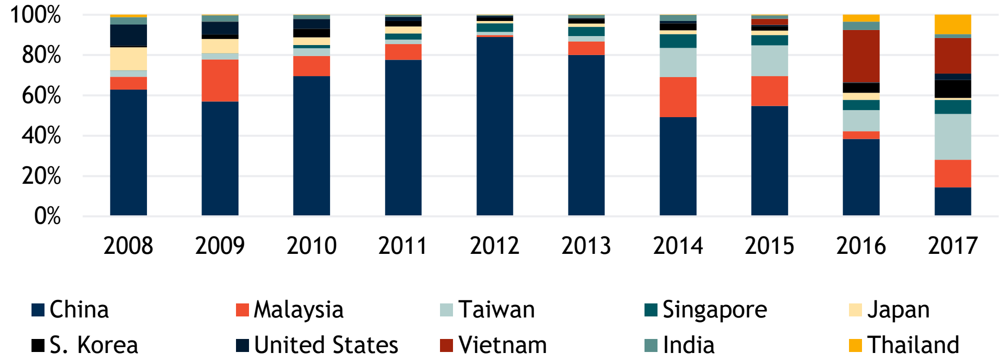


Table 3-4 lists the market shares of the four leading countries in cell and module production. China holds a dominant position in both markets despite EU and US trade restrictions. Taiwan is the second largest supplier of cells, without having an equivalent share in the module trade. This success is largely based on the superior quality of Taiwanese cells (PV Magazine, 2018). Leading cell manufacturers from Taiwan include Neo Solar Power, Gintech and Suntech Power. However, due to advances in Chinese technology and economies of scale, the market share of Taiwanese cell manufactures fell from 18% in 2013 to 12% in 2017 (IEA PVPS, 2018).

Table 3-4 Country market shares for PV cell and module production, in 2017 (IEA PVPS, 2018).

Cell production		**Module production**	
Country	**Market share (%)**	**Country**	**Market share (%)**
China	69	China	72
Taiwan	12	S. Korea	7
Malaysia	7	Malaysia	6
S. Korea	5	Japan	2
CR4 country	**93**	**CR4 country**	**87**

3.3.3 Political risk

Table 3-5 scores the top manufacturing countries of photovoltaic devices based on long-term political risk (The Global Economy, 2018). Risk of political instability ranges from very low to moderate across the Asia-Pacific region. Vietnam scores moderately for political risk, but it has been improving over the past few years (2015-2017). Meanwhile, Malaysia saw its political ranking decline over the same period.

Table 3-5 Political risk index, on a scale of 1 (low risk) to 7 (high risk) (The Global Economy, 2018)

	Risk indicator (1-7)				
Country	**2014**	**2015**	**2016**	**2017**	**Risk**
China	2	2	2	2	
Taiwan	1	1	1	1	
Malaysia	2	2	3	3	
Japan	1	1	1	1	
Vietnam	5	5	4	4	
Thailand	3	3	3	3	

South Korea	1	1	1	1	
Singapore	1	1	1	1	

3.3.4 Ease of market entry

Table 3-6 outlines key factors contributing to ease of market entry for PV cell and module production. The assessment concerns standard c-Si technology as used in large scale PV systems. Market entry barriers for tailor-made solutions, e.g. building-integrated photovoltaics (BIPV), are not included as these supply niche markets.

Table 3-6 Ease of market entry indicated low ease, medium ease and high ease in red, yellow and green respectively

Factors		Assessment
Start-up capital requirements		The start-up capital required for photovoltaic cells and modules is high, as was confirmed by industry experts. In a study from 2015, it was calculated that the investment costs of a competitive 2 GW module factory would total US $2 billion, including polysilicon production, or US $1.4 billion, excluding polysilicon production (Powell, 2015). Capex accounts for over 80% of investment costs, which comprises property, plant, equipment and facility engineering costs. In the example presented in the publication, initial capex pertaining cells is approximately 30%, or US $0.6 billion; and 13%, or US $0.26 billion, for modules.
Fixed costs		Fixed costs are low. Capex accounts for less than a quarter of the module price, including the cumulative costs of upstream elements. From polysilicon to module production, revenue streams are largely dictated by variable costs. Materials constitute at least half of these costs (Powell, 2015).
Entry protection (patents, rights, etc.)		For c-Si technology, the role of intellectual property is considered low. Solar PV has become a commodity where economies of scale and learning-by doing are favoured over innovation as cost-reduction factors. This is supported by the fact that many manufacturers are developing the same types of technology. The principles of c-Si PV were established decades ago, and so the patents protecting fundamental cell and module technology have long expired (ClearViewIP, 2012) (Tan, Sun, Ye, Liu, & Su, 2014).
Economies of scale		The benefits from economies of scale are high. Prices for PV modules have been declining in accordance with what is known as Swanson's law of photovoltaics. On average, doubling the production capacity results in a twenty percent price reduction for modules (The Economist, 2012) (Kavlak, McNerney, & Trancik, 2018). In the current market, this means that GW scale production capacity is necessary to compete at a global level.

Factors		Assessment
Learning curve advantages (or experience curve)		Learning curve advantages are of medium importance. In solar PV, the learning curve (either by doing or by innovating), sometimes referred to as experience curve advantages are not as critical as economies of scale effects, although it is sometimes difficult to differentiate between the two (Kavlak, McNerney, & Trancik, 2018). Advantages pertaining to experience are generally seen in the initial phase of operation, known as the ramp up phase. The ramp up phase is defined as the required period of time for a production or assembly line to reach full capacity after commissioning of the installation and all its equipment. As demonstrated by the rapid foreign expansion of Chinese PV manufacturers, this can be achieved in 6 – 12 months. Since the industry is highly automated, factory output is mostly limited by equipment, rather than human experience. However, this is not to say that expertise is trivial. A successful ramp-up phase can make-or-break an investment. With the decline of the EU PV cell and module industry, experts acknowledge that there has been a loss of expertise in the EU and thus there is an increased risk of technology dependence.
Access to distribution		Distribution of photovoltaics has no particular limitations neither for PV cells or PV modules.

Regarding market entry, the largest obstacles for PV module and cell production are start-up capital requirements and economy of scale effects. Labour costs, which are often lower in foreign regions, should not limit market entry for PV module and cell production in Europe. The extraordinary development of the Chinese market is the result of a collaborative effort between education, industry and government. From expert surveys, it was concluded that an adequate framework is needed for the EU PV market to become competitive. Overall, the ease of market entry is rated low for PV cell production and medium for PV module production. The distinction is made between the two here since the start-up capital requirements for module manufacturing are significantly lower than for cell manufacturing and because experts indicated that it is easier overall to set-up a module manufacturing plant than a cell manufacturing plant.

3.3.5 Availability of substitutes

In this assessment, substitutes are defined as alternatives to c-Si technology. An alternative can be a variation on c-Si, such as amorphous silicon, or an intrinsically different technology. Substitution of the semiconductor, or photovoltaic material, requires a complete redesign of both the cell and module structure. This is due to the unique electrical and optical properties of each material. Moreover, alternative technologies do not necessarily have to exhibit the cellular structure that is typical for c-Si modules. Therefore, no distinction is made between cells and modules regarding substitution. The availability of substitutes is assessed in Table 3-7.

Table 3-7 Availability of substitutes in terms of low, medium and high potential as a substitute, in red, yellow and green, respectively

Factor		Assessment
Availability of direct substitutes		Substitutes for c-Si cells and modules have been in development for many years. These include second generation thin-film technologies (CdTe, CIGS and amorphous silicon (a-Si)) and several others that are still in development including perovskites, organic PV and quantum dot. Thin-film technologies held a market share of 5% in 2017 (Fraunhofer ISE, 2018) and have a high potential for adequate substitution.

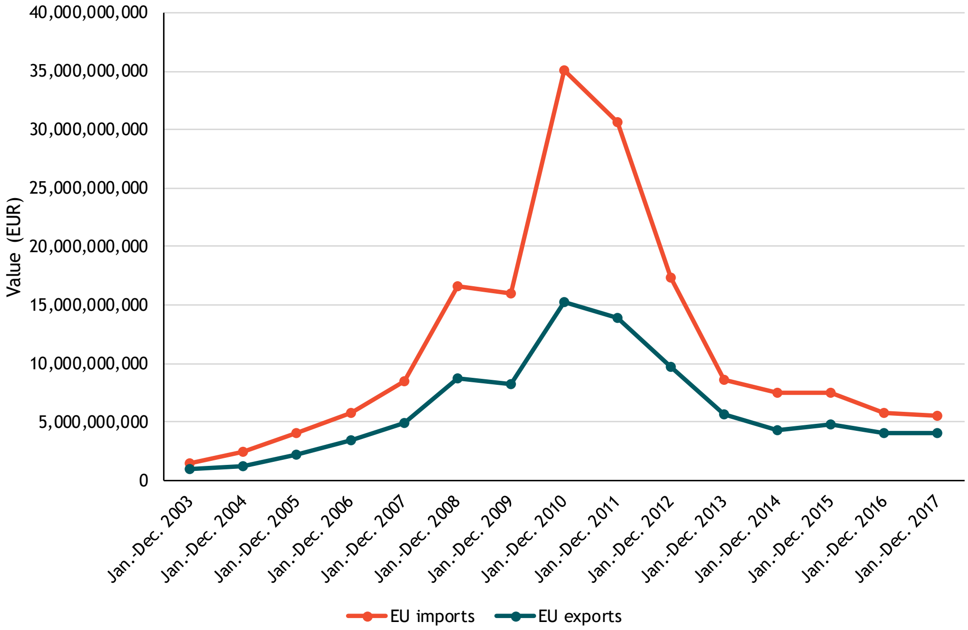
Factor		Assessment
Technology readiness level (or commercial readiness level) of substitute		CdTe, CIGS and a-Si are commercially available technologies. In terms of performance (power output over cost), CdTe and CIGS can compete with c-Si technology, whereas a-Si mainly supplies a niche market. First Solar (headquartered in the USA) has been successfully developing CdTe modules for commercial and utility-scale PV. This exemplifies a high level of technology readiness and thus a <u>high</u> potential for adequate substitution.
Homogeneity with the currently used element		The available substitutes do not differ from current c-Si technology in terms of operation or installation. Balance of system components are also identical in PV systems with thin-film modules; <u>high</u> potential for adequate substitution.
Price differential		The price differential for c-Si modules and thin-film substitutes is <u>low</u>. Average module prices (in USD / Watt) for poly c-Si modules are about 10-20% lower than thin-film modules, whereas mono c-Si has a comparable price (PVinsights, 2018).
Practical barriers to substitution		Two barriers for substitution were identified. Firstly, the production capacity for thin-film modules is insufficient for short-term substitution of c-Si. Secondly, supply of raw materials for CdTe and CIGS is much more restricted than for c-Si, which may lead to future dependencies; <u>low</u> potential for adequate substitution.
Complexity of distribution		Distribution of the substitutes adds no particular complexity; <u>high</u> potential for adequate substitution.

Based on this assessment the availability of substitutes for c-Si solar cells and modules is considered <u>high</u>.

3.3.6 Competitiveness trends

Trade in solar cells and modules is reported under the category photosensitive semiconductor devices in Eurostat – Prodcom. Although this category does not only include solar cells and modules it is still considered a fairly accurate estimate for analysing the import and export volumes of solar cells and modules. Figure 3-5 shows that the EU is a net importer of solar cells and modules, consistent with the earlier analysis of the EU's external dependence. It is important to note that the EU has been a net importer of solar cells and modules since the early days of solar PV development (2003). Initially this was driven by the generous incentives for PV deployment in the EU, which led to rapid market growth that could not be serviced by EU suppliers only and made the EU a net importer. From 2008 onwards, the competitiveness of the EU industry also deteriorated due to a combination of factors, including a temporary raw material shortage (for silicon) that affected EU manufacturers more than their Chinese counterparts, strong industry development and associated economies of scale for Chinese manufacturers (Trinomics, 2017). Furthermore, EU manufacturers already faced higher labour costs than in some competing countries. When the market for solar PV in the EU declined and the foreign market started to pick up, a lack of competitiveness of EU manufacturers had been established and a trade deficit persisted. Looking at the last five years (2013 to 2018), the trade deficit has remained relatively stable. So overall, we conclude that while the EU solar cell and module manufacturing industry struggles to compete internationally, there are no signs of further worsening of its competitiveness. Hence, the competitiveness is judged to be stable and does not point to a further increase of the dependency on solar cell and module imports.

Figure 3-5 Import and export values - photosensitive semiconductor devices including solar cells, photo-diodes, photo-transistors, etc.



Source: Eurostat - Prodcom. Data extracted on 22 August 2018. Category: 26112240 - Photosensitive semiconductor devices INCLUDING: - photovoltaic cells whether or not assembled in modules or made up into panels - solar cells - photodiodes, phototransistors, photothyristors or photocouplers - laser sensitive devices, infra-red and other photo sensitive devices EXCLUDING: - light emitting diodes (LEDs)

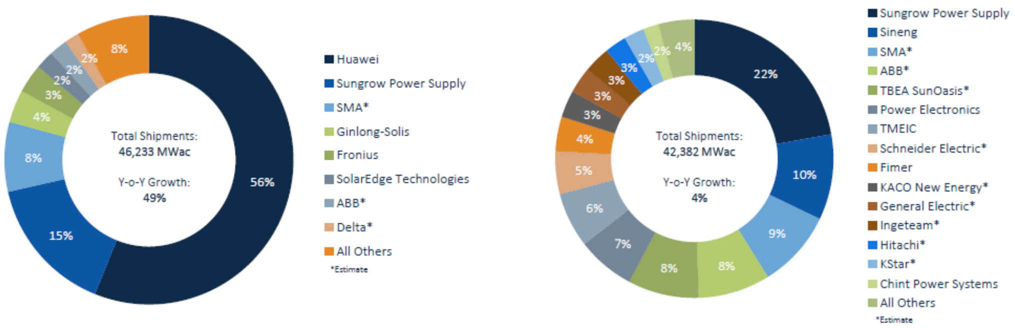
3.4 Inverters

The main function of PV inverters is to convert direct current (DC) power to alternating current (AC) power. PV panels produce DC power, whereas AC power is required by the off-taker – the transmission and distribution systems (the electrical grid) or the point of consumption in case of off-grid systems. Inverters have developed over time to provide a growing number of additional services such as maximum power point tracking (MPPT), data monitoring, anti-islanding protection, as well as various grid stabilisation services (e.g. low-voltage ride through, active and reactive power control), thus becoming very sophisticated technologies as well as the second-largest hardware cost in a PV project after PV modules.

Two different types of inverters are typically used in PV systems, namely: stand-alone inverters connecting a battery for storing the DC power produced by the PV array to the AC appliance (in some systems the two elements are integrated); and grid-connected inverters connecting the PV arrays to the electrical grid, via one or more transformers. The first type of inverter is generally simpler, as it does not need to provide most ancillary services (e.g. black start) provided by grid connected inverters. The use of stand-alone inverters in the EU is linked to the residential and commercial PV market, with utility-scale plants being mostly connected to the grid. As both residential and utility-scale PV systems are present in the EU, the assessment will include both technologies.

A further distinction can be made between micro, string and central inverters. Micro inverters are connected to a single or a few modules, string inverters convert electricity from a few strings of modules connected in series, while central inverters allow for a much higher input voltage, and thus collect electricity from a larger number of strings grouped through combiner boxes. Global production of string and central inverters is currently similar in terms of shipments (see Figure 3-6, presented here in terms of their nominal output capacity), with global shipments for string inverters in 2017 totalling 46,233 MWac, and global shipments for central inverters in 2017 totalling 42,382 MWac (GTM Research 2018). Shipment of micro inverters in 2017 stood at 1,034 MWac (GTM Research 2018). While the relative shipments of one type over the other may shift, the assessment will focus on the two most common technologies, string and central inverters.

Figure 3-6 Global string and central inverter shipments in 2017 (Source: GTM Research 2018)



3.4.1 EU external dependence

EU external dependence on inverters is calculated as the proportion of net imports relative to the apparent consumption within the EU.

Net imports

Net import of PV inverters in the EU is estimated as the difference between total PV inverter shipments to Europe (by nominal output capacity) minus total PV inverter shipments by European manufacturers to countries outside the EU. Table 3-8 provides the net imports.

Table 3-8 Inverters net imports by the EU (based on GTM Research's 2018 "Outlook for inverters shipment" (GTM 2018)

Year	2015	2016	2017
Shipments to Europe (excluding Turkey), GWac	7,300	7,440	9,984
Shipments from Europe, GWac	12,688	16,383	18,577
Net imports (total imports – total exports), GWac	**-5,388**	**-8,943**	**-8,593**
Global shipment total (for reference), GWac	**59.7**	**80.4**	**98.6**

As can be observed by the figures, EU manufacturers are net exporters of inverters, which leads to an external dependency of 0%. The total shipments to Europe in 2017 exceed the 2017 capacity additions in Europe (resp. 9.98 GWac versus 5.3-8.6 GWdc) since inverters are not always directly used and PV capacity additions are either not fully reported (local off-grid and small installations are often not reported) or are reported in the year of start of commercial operation rather than in the year of construction. Note that the global inverter shipment (98.6 GWac in 2017) is in the same range as the 2017 capacity additions global (92.5-98.9 GWdc) (albeit in different units, namely GWac for inverters and GWdc for installations). The absence of critical dependencies was further confirmed though the interviews conducted for this study

3.4.2 Market concentration

CR4-firm

The market share of the four largest firms in 2017 was extracted from GTM Research's Global solar PV market shares and shipment trends (GTM Research 2018). This publication provides statistics on the market share of the largest global inverter manufacturers both in terms of shipments and in terms of revenues (see Table 3-9).

Table 3-9 Market concentration / CR4-firm, from (GTMResearch inverter concentration, 2016)

Global PV Inverter Market Share by Shipments (MWac)		Global PV Inverter Market Share by Revenue ($M)	
Company	**Market share**	**Company**	**Market share**
Huawei	26.4%	Huawei	20.2%
Sungrow Power Supply	16.7%	SMA	13.0%
SMA	8.7%	Sungrow Power Supply	10.6%
ABB	5.6%	SolarEdge Technologies	8.4%
CR4-firm	**57.4%**	**CR4-firm**	**52.2%**

Ranking by revenues gives ranking advantages to companies that sold higher volumes in the early parts of the year, in the case that prices fall throughout the year (GTM Research 2018). As such, ranking by shipment gives a more accurate representation of market concentration (for the purpose of this analysis), which leads to a CR4-firm of 57%. Looking at statistics for 2015 and 2016, the present ranking (order and names of companies in the top 4) is confirmed (companies have stayed pretty much at the same level over time), although relative shares vary over time.

CR4-country

The same source used for the CR4-firm indicator was used to determine the CR4-country indicator. The ranking of inverter manufacturers by shipment in 2017 was integrated with the country where the company's headquarters is located, as indicated on each companies' website. The results are shown in Table 3-10.

Table 3-10 Market concentration / CR4-country (GTMResearch inverter concentration, 2016)

Country	Companies	Collective market share
China	Huawei, Sungrow Power Supply, Sineng, TBEA SunOasis, Ginlong-Solis, KStar, Chint Power Systems	57.2%
Germany	SMA, KAKO New Energy	10.8%
Switzerland	ABB	5.6%
Spain	Power Electronics, Ingeteam	4.4%
CR4-country		**78.0%**

As shown in Table 3-10, the inverter industry is highly concentrated, with the four largest companies by shipments delivering 57.4% of the global inverters, and production in the top four countries by shipment comprising 78.0% of the global total in 2017, of which over half was produced in China. The risk of market concentration was further confirmed through interviews with IHS Markit, which indicated that increasing concentration (over time) is likely to be a trend that will continue in the future years. However, with one of the top four producers headquartered in Germany (an EU Member State), 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 deemed to favour rather than threaten Europe's economy.

3.4.3 Political risk

China

This assessment is based on the 2017 long-term political risk index (The Global Economy, 2018), which has consistently indicated a low risk of 2 for China over the period 2014-2017. This is typically considered an acceptable level of political risk.

3.4.4 Ease of market entry

The example of Huawei, which entered the PV inverter market in 2013 and positioned 9th in the global ranking by shipment for the same year, then climbed to the 3rd place in 2014 and has topped the ranking between 2015 and 2017 (GTM, Huawei 2017, GTM Research 2018), exemplifies the importance of considering ease of market entry in the assessment of dependencies.

The analysis of ease of market entry has been carried out using a standard set of indicators as detailed in the step-by-step manual section 3.4. Scoring has been based on available literature, sector interviews, and expert judgement. The results of the assessment are presented in Table 3-11.

Table 3-11 Ease of market entry for PV inverters indicating low ease, medium ease, high ease of entry in red, yellow and green resp.

Factors		Guidance on scoring (High, medium, low)
Start-up capital requirements		Expert interviews confirmed that the inverter market is characterised by high start-up capital requirements, which leads to a low ease of entry.
Fixed costs		No reliable information found on the share of fixed versus variable costs for inverter manufacturing. Hence, no assessment on this criterion has been made.
Entry protection (patents, rights, etc.)		The current fragmentation of the inverter market shows how product development is not significantly hindered by protection mechanisms. Moreover, according to GTM Research, differentiation is accelerating, with additional services such as building energy management, battery integration, and uninterruptible power supply becoming increasingly prominent in an effort by manufacturers to pursue higher margins. This results in a high ease of market entry.
Economies of scale		According to expert interviews, the importance of economies of scale is high, which results in a low ease of market entry.
Learning curve advantages (or "experience curve)		Designing and manufacturing inverters requires significant R&D support and is subject to several international standards regulating inverter performance and safety, hence the learning curve advantages are considered strong. This results in a low ease of market entry.
Access to distribution		With utility-scale inverters being mostly shipped by manufacturers to the project site, and the residential market being populated by a high number of distributors, no significant barriers are observed in relation to access to

Factors		Guidance on scoring (High, medium, low)
		distribution. This results in a high ease of market entry.

Overall, the ease of market entry is deemed to be medium, as the inverter industry requires high capital costs and expertise, but large corporations already involved in the development and production of electronic goods are not significantly affected by these barriers.

While it is true that SMA retained its position in the top three ranking of inverters manufacturers in the last several years, there is always the possibility that new or existing firms will increase shipments and grow their market share.

3.4.5 Availability of substitutes

The availability of substitutes ultimately depends on the specific type of inverter and can be interpreted in different ways: substitution of an inverter by one manufacturer with the inverter produced by another manufacturer, or substitution of string with central inverters and vice versa. Inverters as a technology cannot currently be substituted with a different technology in PV systems.
A general assessment is presented in Table 3-12.

Table 3-12 Availability of substitutes for PV inverters indicating low-, medium- and high potential in red, yellow and green resp.

Factors		Guidance on scoring
Availability of direct substitutes	(yellow)	No alternatives to inverters as a technology currently exist in the PV industry, and therefore the analysis of substitutes is limited to different types of inverters, in particular string and central inverters (micro inverters do not currently have a significant market share). While the replacement of string with central inverters and vice versa during the operational life of a plant is not considered a workable option, new plants are increasingly exposed to the choice between different inverter sizes. Recent market trends in fact indicate that three-phase string inverters are increasingly being considered for large-scale PV installations that have traditionally relied on central inverters. On the other hand, central inverters are becoming more modular in order to improve design flexibility and minimize redundancy. Overall the score associated to this indicator is medium.
Technology readiness level (or commercial readiness level) of substitute	(green)	No alternative technology to inverters currently exist. However, several manufacturers located in different geographies are able to produce both central and string PV inverters, which can serve as substitutes. As such, the availability of substitutes from this point of view is high. The replacement of installations already built with new inverters is also considered easy since inverter availability in several power ranges is high and electrically there should be minimal differences (meaning one could replace an inverter of manufacturer A with a similar inverter of manufacturer B)
Homogeneity with the currently used element	(yellow)	As no alternatives to inverters as a technology currently exist in the PV industry, once again the analysis of substitutes is limited to different types of inverters, in particular string and central inverters. While both types deliver the same result, i.e. AC current and ancillary services, each require a specific configuration of the BoS in order to achieve optimal performance and is therefore not common to replace them during the operational phase of the project. However new plants can now more readily choose between inverters of different sizes at the design stage, with balance-of-system components to support each configuration being readily available. For this reason, homogeneity is deemed medium.

Factors		Guidance on scoring
Price differential		The price per watt of several types of inverters has grown increasingly similar, with central and string inverters for commercial and utility-scale system now in competition (GTMResearch 2018). For this reason, price differential is not deemed to constitute a barrier to substitution.
Practical barriers to substitution		No significant practical barriers to substitution between different types of inverters are observed at project design stage, with BoS components supporting each configuration being readily available. This results in a high potential for adequate substitution. Substitution of string/central inverters during the operational phase is however not commonly observed. For this reason, barriers to substitution are deemed medium.
Complexity of distribution		No significant barriers are observed in relation to the complexity of distribution when considering substitution of one type of inverter with another; this results in a high potential for adequate substitution.

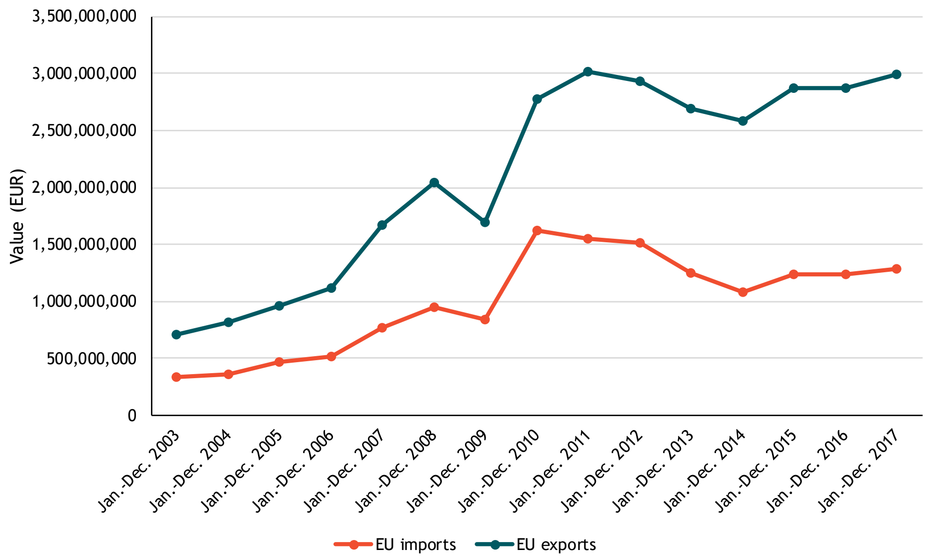
Based on the results of the above assessment the overall conclusion is that substituting one type of inverter with another is feasible, with the distinction that new plants can choose between central or string inverters, different sizes and manufacturers, while operational plants mostly upgrade old inverters with new models of the same type, from the same or a different manufacturer. Therefore, the availability of substitutes for different types of inverters is considered high. However, it should be reiterated that the inverter itself cannot be substituted by another technology/device. Hence, in case a dependency for all types of inverters would emerge, availability of substitutes should be considered low.

3.4.6 Competitiveness trends

Trade in inverters is reported (in Eurostat - Prodcom) under the categories 'Inverters having a power handling capacity ≤ 7,5 kVA' and 'Inverters having a power handling capacity > 7,5 kVA'. For this analysis we have selected only the latter category (>7,5 kVA) because the inverters with lower capacity also include inverters used for applications other than solar PV. Hence, the category of inverters with higher capacity are more representative for the competitiveness of the EU solar PV inverter trade.

Figure 3-7 shows that the EU is a net exporter of inverters, consistent with the earlier analysis of the EU's external dependence. Moreover, the EU trade surplus for inverters is very large and shows no signs of decreasing. Hence, the competitiveness of EU inverter manufacturers is high and the trend in the competitiveness is judged to be stable.

Figure 3-7 EU import and export values - Inverters having a power handling capacity > 7,5 kVA



Source: Eurostat - Prodcom. Data extracted on 22 August 2018. Category: 27904155 - Inverters having a power handling capacity > 7,5 kVA for the years 2016 and 2017. For the years before 2016, the category had a different code: 27115055 - Inverters having a power handling capacity > 7,5 kVA.

3.5 Conclusions

3.5.1 Assessment of dependencies

Table 3-13 provides a summary of the dependencies that have been assessed for solar PV.

Table 3-13 Summary and scoring of dependencies for solar PV

Dependency	Import share	Market concentration (CR4 Country)	Market concentration (CR4 Firm)	Political risk	Ease of market entry	Availability of substitutes	Competitiveness trend
PV Cells	> 90%	93%	<40%	Low	Low	High	Stable
PV Modules	65-80%	87%	34%	Low	Medium	High	Stable
PV Inverters	0%	78%	50-60%	Low	Medium	High	Stable

Solar PV cells are confirmed as a critical dependency

The analysis confirms solar PV cells are a critical dependency, as was suggested in the broad brush assessment conducted as part of this study. The EU imports most of its solar PV cells and despite the minimum import prices that were in effect between 2013 and 2018 and the resulting diversification of countries supplying the EU, the global supplier market for solar cells remains concentrated in a few countries (China and Taiwan in particular). The assessment further reveals some factors that reduce the risk of this dependency, such as the lower concentration in terms of companies, the low political risk associated with the supplying countries and the high availability of substitutes, but also some factors that increase the risk of the dependency such as the low ease of market entry. Overall, we conclude that solar cells are a critical dependency with a medium risk associated with it.

Solar PV modules are a critical dependency, albeit slightly less critical than solar cells

For solar modules, the results are largely similar to solar cells. The main difference is that the EU has a slightly stronger position in module manufacturing and hence a lower external dependence. Furthermore, the market concentration for modules is slightly lower and it is easier to enter the market. Overall, we conclude that solar modules are a critical dependency per the definitions used in this study, but with a relatively low risk associated with it.

For solar inverters there is a strong EU industry and no dependency on external suppliers

For solar inverters the potential dependency or emergence of a dependence reported by industry experts was not confirmed by our analysis. The EU has no external dependence for inverters and retains a strong competitive position in this market. Hence, there is no critical dependency and no need for policy intervention.

3.5.2 Industry perspective on dependencies

The outcomes of this independent assessment of solar PV technology dependencies is consistent with the viewpoints of industry on dependencies, which emerged during the interviews held in this study. The main viewpoints of the industry are:

EU dependency on solar cells and modules is a risk for EU industrial leadership in renewables but not for security of supply

The industry recognises the EU's dependency on solar cells and modules but has very different opinions on the need for governments to act. EU-based manufacturers are strong proponents of policy intervention to improve their competitive position versus foreign manufacturers (Chinese manufacturers in particular). EU-based installers on the other hand do not consider reliance on non-EU suppliers to be a major risk as the cell and module manufacturing market is highly competitive with sufficient suppliers to choose from. Hence, they do not see this external dependency as a risk and are against any trade measures that would increase the price of imported cells and modules. Overall, we conclude that rebuilding the EU PV cell and module manufacturing position and thereby regaining industrial competitiveness would require public support measures, but that public intervention is not needed for safeguarding a secure supply of solar cells and modules.

There is no current dependency for inverter manufacturing, but capacities tend to shift to areas outside the EU

The industry perspective on inverter manufacturing is consistent with our analysis in that there is no current dependency on external supply. However, some independent experts indicated that there is a tendency to move production capacities to countries with high demand (current or forecasted), such as China, India, South Africa and Brazil. If this trend continues, they warn that a dependency may emerge.

4 Detailed assessment: Battery energy storage

4.1 Introduction

The world is experiencing a rapid transition in the energy sector with a steady growth of intermittent renewable energy sources (RES) such as solar and wind power generation. In line with this increased share of intermittent RES in the final energy mix it becomes vital to facilitate flexible supply and demand, which is balanced at every instant. Battery energy storage is positioned to become an important part of the solution to overcome this challenge by aiding reliable integration of RES in the grid along with solutions to mitigate the variability of RES, grid flexibility and frequency imbalances. The annual installed stationary battery energy storage capacity in 2018 is estimated to be 2 GW with a forecasted value of 14 GW by the year 2023 (IRENA, 2015). The rise in penetration of Electric Vehicles (EVs) in the mobility sector is another major factor behind the increased demand for battery energy storage systems. In 2017 1.1 million EVs were sold and in 2030 sales forecasts rise to 30 million EVs (BNEF, 2018).

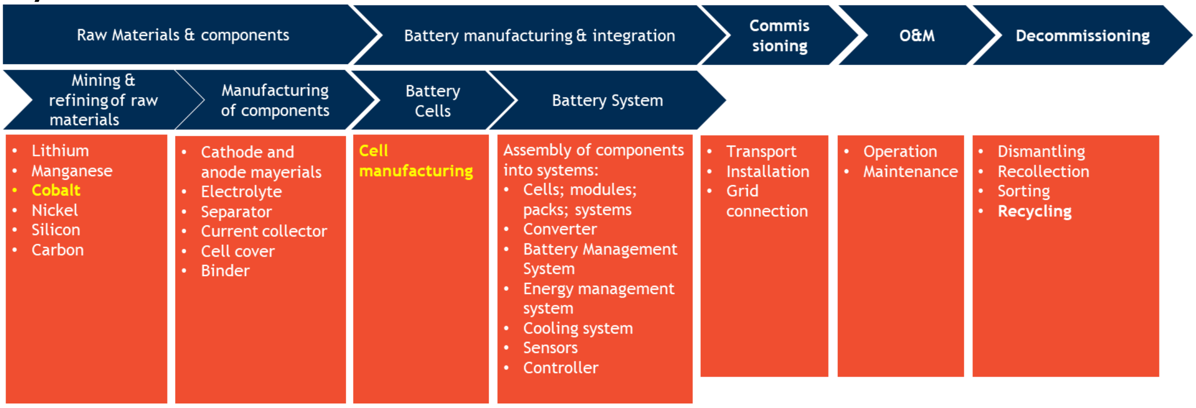
The EU has expressed ambitions to realise a Li-ion battery manufacturing capacity in 2030 of 50 GWh for EVs and of 10 GWh for stationary, large scale energy storage systems (European Commission, 2016). Subsequently the European Battery Alliance (EBA) has been established, which is a cooperative platform that brings together the European Commission, interested EU countries, the European Investment Bank, stakeholders from the whole battery value chain and other innovation actors (European Battery Alliance, 2018) (Faure-Schuyer, 2018). The EBA has the objective to create a competitive manufacturing chain in Europe with sustainable batteries at its core in line with the projected global battery market value of EUR 250 billion/year in 2025 (European Commission, 2018). In addition, the EU wants to have an economically viable recycling industry with 85% collection rate and 50% recycling efficiency to be compliant with Directive 2006/66/EC (European Commission, 2016), (Circular Energy Storage, 2018).

Today the upstream side of the Li-ion battery value chain (mining and refining of raw material, manufacturing of components, and battery cells manufacturing), which is mostly cost driven, is not well established in the EU. The downstream side of the value chain (system manufacturing and integration, along with commissioning and decommissioning) is value driven, thus depending on ability to comply with specific design, performance and control requirements of application. The EU has more expertise on this downstream side of the value chain. In addition, the EU has the potential to develop a Li-ion battery recycling industry, but it will be hard to compete with the development of the Chinese recycling industry, since today the largest share of Li-ion batteries at end-of-life is already recycled in China, benefitting from the growing demand for raw materials from the Chinese domestic battery material industry (Melin, 2017).

In this report, the focus is on li-ion technology as this technology maintains leadership in terms of performance, maturity level, market share and predicted market growth as compared to other battery technologies. The complete value chain of Li-ion batteries is investigated based on interviews carried out with battery energy storage experts from companies with headquarters in the EU (see expert list in Annex A), scientific publications and reports (see Annex B: References).

4.2 Value chain and main dependencies

Figure 4-1 Battery energy storage value chain with potential critical dependencies highlighted in yellow



The battery energy storage value chain can be enumerated into the following consecutive steps as shown in Figure 4-1:

- **Raw materials extraction & components production**: this step involves the mining and refining of raw materials used in Li-ion batteries, such as lithium, manganese, cobalt, nickel, silicon and carbon. In addition, this section also comprises the manufacturing of components such as separators, electrode materials (anode/cathode), electrolytes, sensors, current collectors, cell covers and binders;
- **Battery manufacturing & integration**: in this step the main components are manufactured into individual battery cells. Subsequently the battery cells are assembled into modules, packs and systems. These assembly steps include the integration of several components to ensure safe and reliable functioning of the battery system (e.g. converter, battery management system, energy management system, cooling system, sensors, controllers);
- **Commissioning: this step includes transport of storage systems to site, installation of the storage system on site and grid connection, all activities necessary to operate the storage system;**
- **Operation and maintenance**: this step includes the products and services required to ensure ongoing operations of the energy storage system;
- **Decommissioning**: this step deals with the necessary activities to ensure recycling and safe disposal of the various elements present in the battery system at the end of its useful life. The involved activities are dismantling, recollection, sorting and recycling. Recycling comprises disassembly, shredding and segregation but also recovery technologies such as pyrometallurgical or hydrometallurgical solvent extraction and electro-refining (Olivetti, 2017).

In the broad brush assessment, critical dependencies for cobalt and battery cells were suggested. As these dependencies are recognised by the industry experts, a detailed assessment on the criticality and risk of these dependencies is provided in this report.

Several interviewees also mentioned recycling as a critical part of the value chain. While recycling is not considered a critical dependency per the definitions used in this study, it is considered a strategic activity for mitigating raw material dependencies. Hence, we provide a high level discussion on battery recycling in this report.

During the analysis, several other potentially critical dependencies were considered but were eventually not selected for a full detailed assessment as their criticality was not confirmed by initial analyses. This concerns the following elements:

- **Lithium**: the criticality of EU dependency on the supply of lithium was assessed because of lithium's essential role for li-ion technology. After an initial review, the supply of lithium is not considered as a critical dependence (European Commission, 2017). Large reserves are found in Chile (7.500.000 tonnes), China (3.200.000 tonnes), Australia (2.700.000 tonnes) and Argentina (2.000.000 tonnes) (Statista, 2017) (USGS, 2018c). These four countries are the most important suppliers, while smaller suppliers also exist. The fact that lithium is supplied in big quantities from several countries makes the supply of lithium non-critical. Moreover, lithium reserves are considered sufficient to cover the expected increased needs (IRENA, 2017);
- **Nickel**: even though nickel is considered crucial for battery technologies in its high purified form, its supply was not considered critical, based on the interviews conducted among the experts in the battery industry. It is also noted that New Caledonia, an overseas territory of France accounted for about 10% of the total Nickel mined in the year 2017 ,just below the Philippines, leading nickel mining with a share of 11% or the world's total (USGS, 2018b). Due to these reasons, Nickel was not identified as a critical dependency;
- **Cell components:** Some stakeholders also pointed to potentially critical dependencies for cell components such as cathode and anode materials, electrolytes and separators. Looking at the EU market share and market concentration for these components, it becomes clear that these markets are relatively concentrated (CR4 country >70%) and that EU companies have a limited market share, which points to a potentially critical dependency (Donald Chung, 2016) (JRC, 2016b). But at the same time, the limited scale of EU battery cell manufacturing results in a very limited EU demand for these components, which may even mean that no dependency exists currently, in case the limited EU capacities for cell components are larger than the limited cell manufacturing capacities. Additionally, there are signs that the development of EU capacities for cell components may be initiated quickly once new cell manufacturing capacities are developed.[13] Furthermore, cell component manufacturing may be integrated into new cell manufacturing capacities, as is the case for several global cell manufacturers. Overall, we conclude that the weak EU position for cell components is largely linked to the lack of cell manufacturing capacities and that it will only become fully clear whether or not a critical dependency exists once EU cell manufacturing is scaled up. Nevertheless, the weak position of EU manufacturers in this part of the value chain should be taken into account in any re-industrialisation strategy.

In the next sections the dependencies for cobalt and battery cells are analysed and discussed in detail together with a high-level discussion on recycling.

[13] See for instance the recent announcement by BASF (https://www.basf.com/global/en/media/news-releases/2018/10/p-18-336.html).

4.3 Cobalt

The EU considers cobalt a critical raw material (CRM) since most of the global cobalt mining production is concentrated in the DRC (58% in 2017) and most of the global cobalt reserves are also found in the DRC (about 50%) (European Commission, 2017). Alternative cobalt reserves are identified in Australia, Canada, Cuba, Philippines, Zambia and Russia (USGS, 2018a).

In Li-ion battery technologies, cobalt is a vital constituent of the cathode material for battery cells. Although cobalt is used for several applications, Figure 4-2 and Figure 4-3 show that the relative cobalt consumption for battery cells has grown significantly: batteries utilize 46% of total cobalt consumption in 2017 as compared to 20% in 2006 (Cobalt Institute, 2018) (GEMC, 2018).

Figure 4-2 Cobalt Consumption by end use in 2006 (GEMC, 2018)

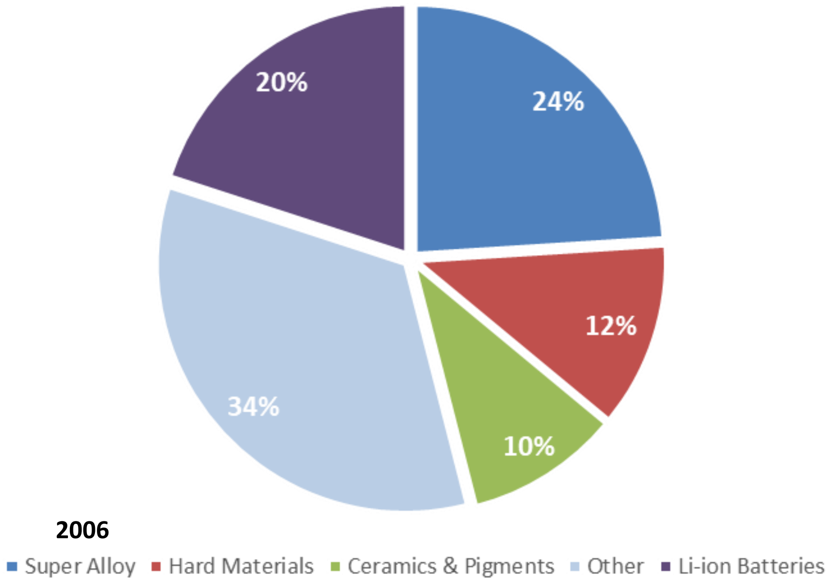
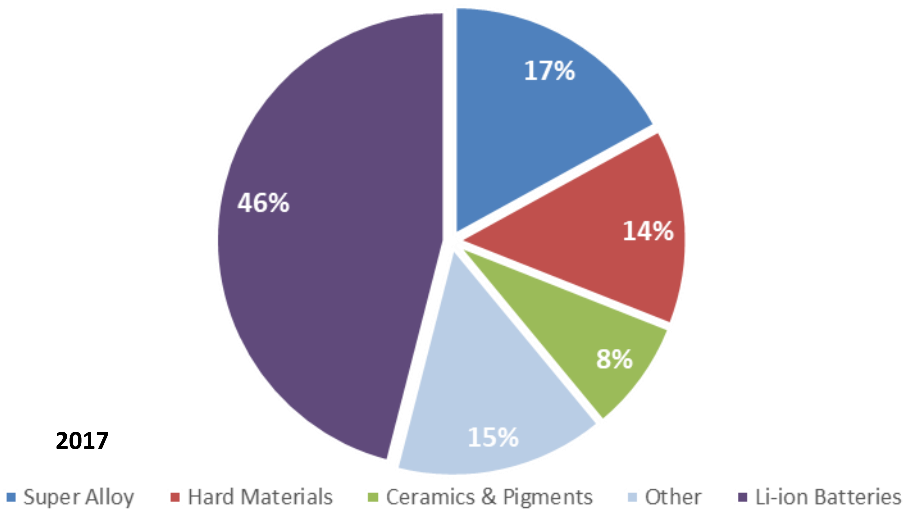


Figure 4-3 Cobalt consumption by end use in 2017 (Cobalt Institute, 2018) (CRU, 2018)



The growing demand of cobalt for battery production is related to the increasing number of electric vehicles. For example, the total amount of EVs in EU in 2013 amounted to 10,000 while in 2017 there were 850,000 EVs in the EU (EAFO, 2018). Globally, the total number of EVs in 2017 exceeded 3 million, whereas it was only 0.4 million in 2013 (IEA, 2018).

This rapidly growing E-mobility industry has led to an unprecedented demand for cobalt which has impacted the supply chain of cobalt. For example, a 68% increase in global cobalt consumption is forecasted between 2015 and 2025 (Spencer, 2016).

4.3.1 EU external dependence

Cobalt is normally mined as a by-product of copper and nickel mining operations. The global cobalt mine production was 114,000 metric tonnes in 2017 (Benchmark Mineral Intelligence, 2018). As mentioned, the major global producer of cobalt is the Democratic Republic of Congo (DRC) which accounts for 64,000 metric tonnes in 2017, that is 58% of the global cobalt mining production. Next is Russia at 5,600 metric tonnes, Australia at 5,000 metric tonnes, and Canada at 4,300 metric tonnes in 2017 (USGS, 2018a).

China has the largest refinery production capacity with 50,000 metric tonnes in 2015; followed by Finland (13,000 tonnes), Zambia (10,000 tonnes) and Russia (6,700 tonnes) (Statista, 2015). The refinery production in China accounts for 58% of global refined cobalt production (Benchmark Mineral Intelligence, 2018).

The EU does not have cobalt reserves, only refinery production capacity in Finland (Freeport) and Belgium (Umicore) (Statista, 2015). Hence, the external dependency for raw cobalt is 100%. Between 2010 and 2014, the EU imported 91% of its cobalt from Russia and 7% from the DRC (USGS, 2018a).

The import reliance of refined cobalt amounts to 32% (European Commission, 2017). The global refined cobalt demand for the year 2017 amounted to 136,000 metric tonnes (Marcelo Azevedo, 2018), with the EU's share accounting for 12% of the total global demand hence accounting for 16,320 metric tonnes (Cobalt Institute, 2018).

4.3.2 Market concentration

Cobalt is primarily mined in the DRC. The production in the DRC amounted to 64,000 metric tonnes in 2017, which is 58% of the global cobalt mining production, and this is expected to increase to 73% by 2023 (Benchmark Mineral Intelligence, 2018) (USGS, 2018a). Other countries with significant cobalt mining capacity include Russia, Australia and Canada (see Table 4-1). The four-country concentration ratio (CR4) for cobalt mining equals 72%.

Table 4-1 Top 4 Cobalt mining countries in 2017 (Statista, 2018)

Country	Mining capacity [tonnes]	Market share
DRC	64,000	58%
Russia	5,600	5%
Australia	5,000	5%
Canada	4,300	4%

It should be noted that most of the mines in the DRC are owned by international enterprises. The major cobalt companies are Glencore, a Swiss mining company with a total production of

27,400 tonnes in 2017 (Glencore, 2018); China Molybdenum, a Chinese mining company with a production of 16,419 tonnes of cobalt in 2017 (China Molybdenum, 2018); and Vale, a Brazilian mining company with a production of 5,811 tonnes of cobalt in 2017 (Vale, 2018).

The four-country concentration ratio (CR4) for cobalt refining equals 71%, as is derived from Table 4-2.

Table 4-2 Top 4 Cobalt refining countries in 2017 (Statista, 2017)

Country	Refinery capacity []	Market share
China	50,000	43%
Finland	13,000	11%
Russia	10,000	9%
Zambia	9,600	8%

4.3.3 Political risk

Table 4-3 scores the major non-EU countries in terms of cobalt mining and refining based on long-term political risk (The Global Economy, 2018).

Table 4-3 Political risk index, on a scale of 1 (low risk) to 7 (high risk)

	Risk indicator (1-7)				
Country	**2014**	**2015**	**2016**	**2017**	**Risk**
DR Congo	7	7	7	7	
China	2	2	2	2	
Russia	3	4	4	4	
Australia	1	1	1	1	
Canada	1	1	1	1	

As mentioned, cobalt supply is currently dominated by mining in the DRC, a country with a high socio-political instability. The dominance of the DRC in cobalt mining is predicted to grow to 74% of global supply in 2021 (USGS, 2018a). There exists concern about sustainable mining in the DRC (Somo, 2016). From the interviews, we learned that mines in the DRC can be assessed by audits according to a framework to ensure sustainable and responsible sourcing of raw materials (Umicore, 2018). The long term political risk analysis states a high risk of 7 for the DRC on a 7-point risk indicator scale. The value of 7 has been constant over the period 2014-2017.

The EU imports 91% of cobalt ore from Russia, the political risk of which has increased in recent years. The long term political risk analysis states a medium risk of 4 for Russia. The value of 4 has been constant over the period 2014-2017.

For cobalt refining, China is the main country of relevance. China has the largest refinery production capacity with 50,000 metric tonnes in 2015 (58% of global refined cobalt production). Today the EU is not importing cobalt from China, however the growing demand for cobalt by China may impact the availability of cobalt for its refinery in the EU. The long term political risk analysis states a low risk of 2 for China. The value of 2 has been constant over the period 2014-2017.

4.3.4 Ease of market entry

Table 4-4 outlines the key obstacles related to market entry for cobalt mining.

Table 4-4 Ease of market entry for cobalt mining

Factors		**Guidance on scoring (High, medium, low ease of market entry resp. green, yellow, red)**
Start-up capital requirements	(red)	The capital intensity for cobalt mining and production is high, as was confirmed by experts and literature study. This is mainly due to costs for machinery and labour, as well as for licenses and permits (for digging, extraction of cobalt and to guarantee safe and sustainable mining).
Fixed costs	(red)	Industry experts consider the fixed costs for cobalt mining to be high.
Entry protection (patents, rights, etc.)	(yellow)	The role of intellectual property is low since the mining process is well documented. However, exploiting new mining locations will be challenging since those which are easily accessible have already been exploited.
Economies of scale	(green)	According to information collected through expert interviews, the benefits from economies of scale are low, which is typical for a raw materials market.
Learning curve advantages (or "experience curve)	(green)	Learning curve advantages are of low importance, since cobalt mining is a mature and established production process.
Access to distribution	(green)	No particular limitations have been identified on the distribution of cobalt. New entrants are not expected to face major barriers in setting up the distribution channels to their clients.

The opening and operation of a new mine is capital intensive and involves costs for machinery, labour, licenses and permits (for digging, extraction of cobalt and to guarantee sustainable mining). The extraction of cobalt ore from nickel and copper ores are labour intensive and environmentally challenging. Exploitation of new mine locations will be challenging, since those that are easily accessible have already been exploited. Under these conditions, ease of market entry is low and this is not expected to change in the short or mid-term.

4.3.5 Availability of substitutes

In this assessment, substitutes are defined as alternative Li-ion battery chemistries with low cobalt content or without cobalt.

Table 4-5 Availability of substitutes for cobalt

Factors		**Guidance on scoring high, medium and low potential for substitution in resp green, yellow and red.**
Availability of direct substitutes.	(yellow)	Substitutes battery chemistries without cobalt that are under development include Lithium Iron Phosphate, Lithium Manganese Oxide and Lithium Titanate batteries. Of the battery technologies that have no cobalt in its composition, none can be considered as mature, limiting the potential for adequate substitution.
Technology readiness level (or commercial readiness level) of substitute	(red)	Most substitute Li-ion battery chemistries have a lower technology readiness level than cobalt-rich battery chemistries. From this point of view the potential for substitution is deemed to be low.

Factors		Guidance on scoring high, medium and low potential for substitution in resp green, yellow and red.
Homogeneity with the currently used element.		Alternative Li-ion chemistries with low cobalt content cannot be incorporated without adjusting operating measures. This limits the potential substitution.
Price differential		The price of substitute Li-ion batteries is unclear, depending on exact chemistries used and their technology readiness level.
Practical barriers to substitution		The main practical barriers identified are the lower energy density and higher safety concerns for substitute Li-ion battery technologies. The potential for substitution on this factor is therefore considered as low.
Complexity of distribution		The complexity of distribution has no limitations, resulting in a high potential for adequate substitution

The criticality of dependence on cobalt supply has been identified by major battery manufacturers. Subsequently, substitute battery chemistries are being developed with low cobalt content and without cobalt. Most substitute battery chemistries have either a lower energy density (Choi & Doron, 2016) (Placke Tobias, 2017), a lower technology readiness level and/or increased safety concerns (the substitute battery technologies are not reliable under constant cycling and show unstable behaviour during different temperature gradients) compared to cobalt-rich Li-ion battery chemistries (Etacheri, 2011) (Bhatt & O'Dwyer, 2015). Thus, substitute battery chemistries are still less suitable for E-mobility applications, which is currently the largest market for Li-ion batteries (Roskill, 2018). Based on this assessment the availability of substitute Li-ion battery chemistries is considered low.

4.3.6 Competitiveness trends

In addition to the factors that determine the current level of critical dependence and the risk associated with that, we also assess any trends in the competitiveness of the EU industry that may influence the level of critical dependence over time. With regard to cobalt ore mining, there is virtually no mining in the EU at present. Hence, an assessment of the competitiveness of the EU mining industry could not be performed.

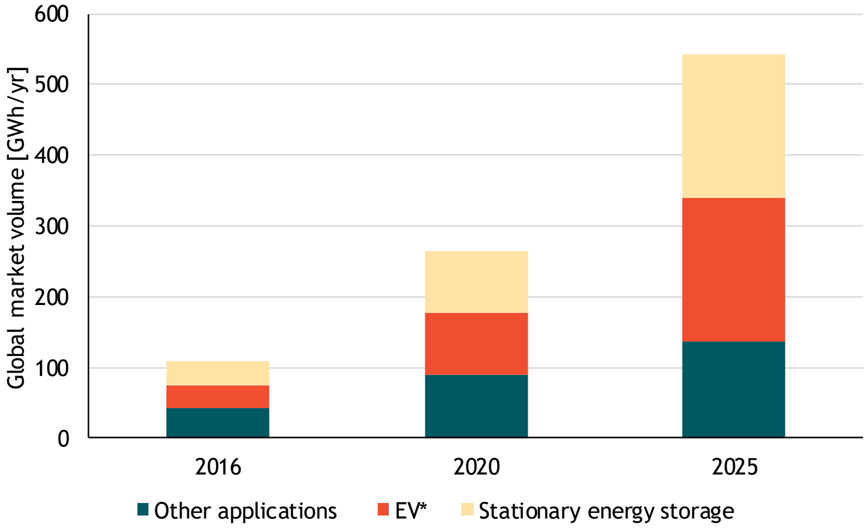
For cobalt refining, there is an active EU industry, most of which is located in Finland and Belgium. Unfortunately, the import and export data of refined cobalt from these two countries have been missing in Eurostat for many years. Hence, a reliable competitiveness analysis for this sector could not be performed.

4.4 Battery cells

There are several types of Li-ion cells available, some with cobalt such as lithium cobalt oxide (LCO), lithium nickel manganese cobalt oxide (NMC or NCM), and lithium nickel cobalt aluminium oxide (NCA), others without cobalt, such as lithium manganese oxide (LMO), lithium iron phosphate (LFP), and lithium titanate (LTO). These Li-ion chemistries differ mainly in energy density, power density, cycle life and resistance to operation outside safe conditions.

Battery cells are produced by a number of large and small manufacturers worldwide for applications ranging from portable electronics to electric vehicles and large scale stationary storage systems. Figure 4-4 shows global market volume forecasts for Li-ion batteries in different applications. The largest share is dedicated to E-mobility. The market for stationary energy storage is predicted to increase significantly towards 2025 (JRC, 2017). Other applications include portable electronics and marine electronics.

Figure 4-4 Global market volume forecasts for Li-ion batteries in different applications (JRC, 2017)



The EV industry is dominated by nickel-cobalt-manganese (NCM) batteries because of their high-energy density, efficiency and safety. Since cobalt is the most expensive material, all battery material developers are trying to reduce the cobalt content.

Tesla has adopted nickel-cobalt-aluminium (NCA) technology developed by Panasonic, as it is a lower cobalt version of NMC. Since the introduction of Tesla Roadster Model S in 2008, Tesla and Panasonic have reduced the cobalt content by 60% (Roadster Model S: 11 kg cobalt per vehicle; Model 3: 4.5 kg cobalt per vehicle) (Benchmark Mineral Intelligence, 2018).

Currently, Li-ion cell manufacturing is dominated by Asia. Figure 4-5 shows the production capacity of Li-ion cells in 2018 and predictions for 2023 (Benchmark Mineral Intelligence, 2018), (Deutsche Bank Markets Research, 2016).

Figure 4-5 Battery Manufacturing Capacity in 2018 and predictions for 2023 by region (Benchmark Mineral Intelligence, 2018), (Deutsche Bank Markets Research, 2016)

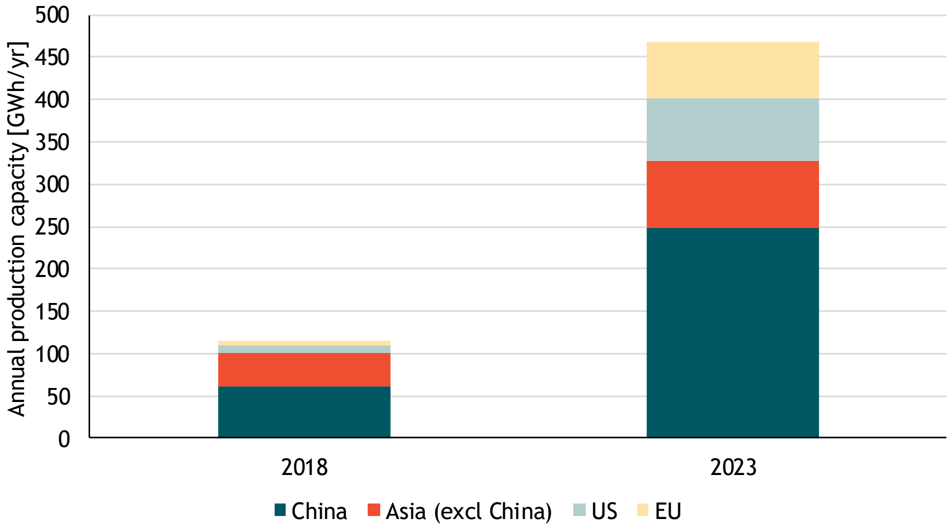


Figure 4-5 shows that in 2023 China will still dominate battery cell manufacturing with a planned capacity of 244 GWh/yr in 2023 (Deutsche Bank Markets Research, 2016).

Today there are some small battery cell manufacturing companies in Europe, such as Leclanché (Switzerland), SAFT (owned by Total, France), AESC (owned by GSR Capital, UK), EAS (Germany) and Litarion (Germany) (JRC, 2016b). Several initiatives for Li-ion megafactories have been announced in Europe, such as TerraE (a German consortium) targeting a production volume of 34 GWh by 2028, and Northvolt a Swedish company backed by Siemens targeting a production volume of 32 GWh by 2023. However, most of the megafactories announced in Europe will be led by mature Asian battery manufacturers (LG Chem, Samsung SDI and SK Innovation are South Korean companies, Panasonic is Japanese, and CATL, BYD and GSR Capital are Chinese).

Given that the upstream side of the battery value chain (material processing and manufacturing of components of cells) is cost-driven. Asia is better situated to compete on costs since it is benefitting from existing production capabilities and market size. The realised price declines for Li-ion battery cells are coming from economies of scale in the Asian manufacturing industry.

Since Asia is already dominating with NCM and NCA chemistries, research in Europe is also focusing on advanced Li-ion chemistries such as lithium metal batteries, all solid-state batteries, lithium sulphur and lithium-air batteries (Nationale Plattform Elektromobilität, 2016). The technology readiness level of these new generations Li-ion batteries is however still low. This requires stable R&D support and high quality testing facilities to test advanced chemistries reproducibly. The BATTEST (Battery Testing) project initiated by European Commission Joint Research Centre's Institute for Energy and Transport aids in addressing this challenge (Pfrang Andreas, 2016).

4.4.1 EU external dependence

The Asia-Pacific region has been dominating lithium-ion battery cell manufacturing worldwide with 88% of the total global production capacity of Lithium-ion battery cells concentrated in China, Japan and South Korea (JRC, 2016b). However, there is no precise data on the imports and exports available, thereby not allowing for a quantitative assessment of the EU external dependence. The data that is available on market concentration (Section 4.4.2) and import/export trade flow between major trading partners aids in drawing a conclusion on the external dependence. First, the market concentration analysis establishes that the top 5 suppliers of Lithium-ion battery cells are outside the EU, together accounting for more than 65% of the global market. The import/export analysis of lithium-ion battery cells substantiates the previous statement since only China, Japan and South Korea have positive trade balance of the top 12 major Lithium-ion battery cells trading countries worldwide (Clean Energy Manufacturing Analysis Center, 2015). Taking these findings into account, we estimate that the EU has a high reliance on external supply.

4.4.2 Market concentration

Table 4-6 shows the market share for battery cell manufacturing by country in 2014 (JRC, 2016b).

Table 4-6 Market share for battery cell manufacturing in 2014

Country	Market share
China	51%
Japan	16%
South Korea	21%
US	7%

The global production capacity for battery cells, including the existing megafactories, was 180 GWh/yr in 2017 and 88% thereof was based in China, Japan and South Korea (JRC, 2016b).

The four-country concentration ratio (CR4) for Li-ion cell manufacturing based on market shares equals 95%, as is derived from Table 4-6.

Table 4-7 shows the market share of battery cell manufacturers by company and confirms that Li-ion cell manufacturing is concentrated in Asia. It should be noted that all companies listed in Table 4-7 have manufacturing plants in China.

Table 4-7 Top 5 Li-ion Battery manufacturers in 2018 (Statista, 2018)

Battery manufacturer	Country	Market share
Panasonic	Japan	21.1%
CATL	China	14.1%
BYD	China	11.0%
LG Chem	South-Korea	10.5%
Samsung SDI	South-Korea	5.6%

The four-firm concentration ratio (CR4) for Li-ion cell manufacturing based on market shares equals 57%, as is derived from Table 4-7.

4.4.3 Political risk

Table 4-8 scores the three countries which dominate Li-ion battery cell production based on long-term political risk (The Global Economy, 2018). Risk of political instability is low for the identified countries from 2014 to 2017.

Table 4-8 Political risk index, on a scale of 1 (low risk) to 7 (high risk)

	Risk indicator (1-7)				
Country	**2014**	**2015**	**2016**	**2017**	**Risk**
China	2	2	2	2	
South Korea	1	1	1	1	
Japan	1	1	1	1	

4.4.4 Ease of market entry

Table 4-9 outlines the key obstacles related to market entry for Li-ion battery cell manufacturing.

Table 4-9 Ease of market entry for battery cell manufacturing

Factors		Guidance on scoring (High, medium, low ease of market entry in resp green, yellow and red)
Start-up capital		The capital intensity for battery cell manufacturing is <u>high</u>, due to the

requirements		costs of manufacturing equipment and advanced technology in terms of production and testing processes. Hence a low easy of market entry.
Fixed costs		High fixed costs: the costs for testing facilities and equipment for high quality processing are very high, resulting in relatively high fixed costs. Hence a low easy of market entry.
Entry protection (patents, rights, etc.)		The major barrier is intellectual property in terms of patents, which are extremely high due to the close competition between different manufacturers for the EV industry to produce batteries with better energy density, safety, reliability and durability. Li-ion battery cell chemistries are also under constant development, driven by the quest for chemistries with low or without cobalt. This results in a low easy of market entry.
Economies of scale		The benefits from economies of scale are high. Asia has been building up large scale manufacturing facilities giving rise to significant price decreases. Europe is lagging behind and has difficulties to enter this cost-competitive market. This results in a low easy of market entry.
Learning curve advantages (or "experience curve)		Battery cell manufacturing is characterised by a challenging learning curve due to the advancements and constant developments in the battery technology used in the cells. EU is strong in early-stage research of advanced Li-ion chemistries. However, there is a gap in terms of deploying new technologies to the market. If Europe does not increase its current Li-ion manufacturing industry, this will hamper the manufacturing industry of the next generation of Li-ion battery cells. This results in a low easy of market entry.
Access to distribution		The requirements for effective distribution are challenging due to the several tests and standards that need to be passed for safe transportation of battery cells.

The ease of market entry for battery cell manufacturing is low as confirmed by industry experts. This is due to a variety of reasons, including the high capital costs of manufacturing equipment and advanced technology in terms of (automatic) production and testing, but also because it is hard to find technically qualified people for setting up a manufacturing industry in Europe. The declining prices of Li-ion cells make it difficult for Europe to enter this cost-competitive market. The lack of security of demand is further hampering the development of a Li-ion cell manufacturing industry in Europe. For E-mobility applications car manufacturers are not willing to guarantee large sales orders because they have high-quality requirements and they are mostly price-driven. The market for stationary storage applications is even more uncertain due to barriers and uncertain regulatory frameworks for entering the electricity market with battery systems. Some interviewees also mentioned the uncertain security of demand outside Europe. For example, China has trade restrictions for companies that want to sell products on the Chinese market.

4.4.5 Availability of substitutes

In this assessment, substitutes are defined as advanced Li-ion battery cells such as lithium metal batteries, all solid-state batteries, lithium sulphur and lithium-air batteries (Nationale Plattform Elektromobilität, 2016).

Table 4-10 Availability of substitutes for battery cells

Factors		Guidance on scoring (High, medium, low potential for substitutes in resp. green, yellow and red)

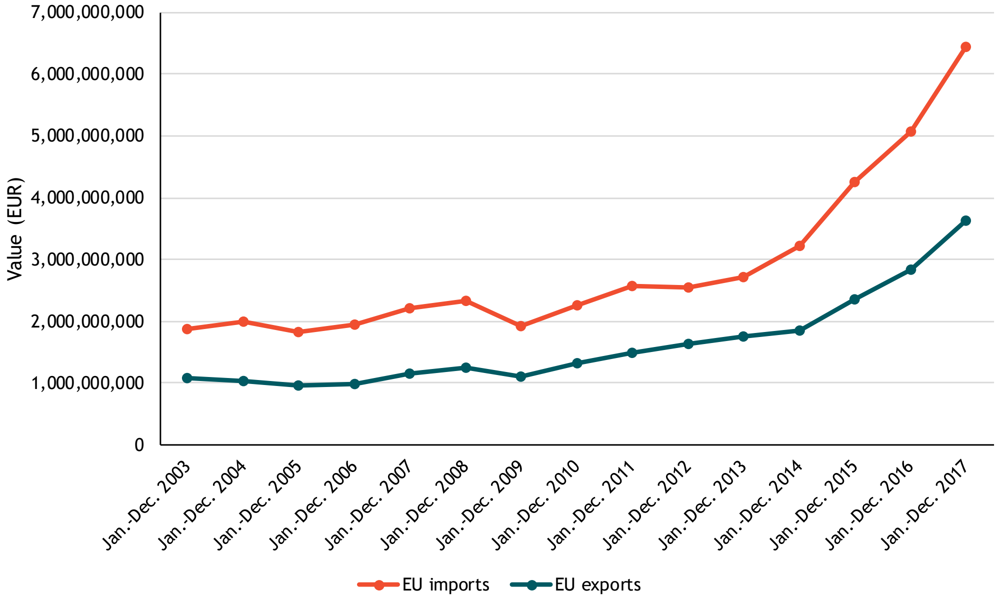
Factors		Guidance on scoring (High, medium, low potential for substitutes in resp. green, yellow and red)
Availability of direct substitutes.	yellow	These advanced Li-ion battery cells are still in research and development stage. In the information gathered from the expert interviews other direct substitutes with comparable technological maturity, energy density and electrical characteristic have not been identified.
Technology readiness level (or commercial readiness level) of substitute	yellow	The technology readiness level of advanced Li-ion battery cells is still considered low, as concluded from the interviews conducted.
Homogeneity with the currently used element.	yellow	Battery systems designed with a particular battery cell would need to be redesigned in terms of packaging, battery management system and safety operational limits
Price differential	yellow	The price of advanced Li-ion batteries is unclear, depending on exact chemistries used and their technology readiness level. These prices are also dependent on the fluctuating cost price of the constituent rare minerals used in the chemical composition of the battery technology.
Practical barriers to substitution	yellow	The practical barriers could be the lower energy density and safety concerns, however that depends on the exact chemistry used in the battery cells and the application it is intended for.
Complexity of distribution	green	The complexity of distribution has no particular limitations, in line with the conclusions derived from the interviews conducted and the major manufacturers of battery cells.

Based on this assessment the availability of substitute Li-ion battery chemistries is considered medium since advanced Li-ion battery cells are still under development.

4.4.6 Competitiveness trends

Trade in Li-ion battery cells is reported (in Eurostat – Prodcom) under the category 'Nickel-cadmium, nickel metal hydride, lithium-ion, lithium polymer, nickel-iron and other electric accumulators', which is broader than Li-ion battery cells only. Hence, these figures cannot be treated as a fully accurate estimate of the trade in Li-ion battery cells but do provide an indication on the competitiveness of the EU battery cells industry. Figure 4-6 shows that the EU import values for this category of products are higher than the export values and that the gap between imports and exports in absolute terms is widening. However, when looking at the ratio between imports and exports it becomes clear that imports have been between 1.5 and 2 times the value of exports over the full time period studied and that no clear trend can be observed. Imports were for instance 2 times the size of exports in 2006, after which this ratio dropped to 1.6 in 2012 and 2013. In the most recent years, imports were 1.8 times greater than exports. Overall, we conclude that no clear trend in the competitiveness of the EU battery cells industry can be discerned and judge its competitiveness to be stable.

Figure 4-6 EU import and export values - Nickel-cadmium, nickel metal hydride, lithium-ion, lithium polymer, nickel-iron and other electric accumulators



Source: Eurostat - Prodcom. Data extracted on 10 September 2018. Category: 27202300 - Nickel-cadmium, nickel metal hydride, lithium-ion, lithium polymer, nickel-iron and other electric accumulators

4.5 Battery recycling

Recycling of Li-ion batteries can offer an alternative supply of raw materials such as lithium, cobalt, nickel, natural graphite and silicon. The recycling rate of Li-ion battery cells depends on the efficiency of collection systems and economics of recovery processes. The EU has expressed the ambition to have an economically viable recycling industry with 85% collection rate and 50% recycling efficiency (European Commission, 2016). The EU battery waste directive (Council of the European Union, European Parliament, 2006) aligns itself with this ambition by setting defined recycling, collection and disposal program along with battery collection rates.

In the EU, the major Li-ion battery recycling companies are Umicore, Accurec Recycling GmbH and Glencore with recycling capacities up to 7,000 tonnes. Interviewees indicated that it is difficult to set up a profitable recycling industry in Europe because there is limited incentive, due to decreasing prices of new batteries. Moreover, it was mentioned during the interviews that the poor collection systems for portable batteries and the reuse prospects for automotive batteries as large scale energy storage solutions limit the current recycling rates. The largest fraction of the 97,000 tonnes of Li-ion batteries per year is recycled in China (67,000 tonnes) and in South Korea (18,000 tonnes) (Circular Energy Storage, 2018). Thus, the recycling business in Asia is already developing rapidly, mainly driven by the growing demand for raw materials by domestic production of battery materials in China. This threatens the development of a recycling industry in Europe.

Therefore, recycling of batteries is not a dependency at present but is identified as a potential future dependency.

Since a dependency has been identified for the supply of cobalt, attention should be paid to the recycling of cobalt. The identified functional end of life recycling rate of Cobalt is greater than 50%, which refers to the recycling process in which the physical and chemical properties of Cobalt are retained as compared to the initial refined Cobalt. The European Commission's Strategic Energy Technologies Information System (SETIS) estimates the recycled content to be 32% (Kotnis, 2018). However most cobalt is not recovered as useful raw material but as stainless steel (Ladenberger, et al., 2018).

4.6 Conclusions

4.6.1 Assessment of dependencies

Table 4-11 provides a summary of the dependencies that have been assessed for battery energy storage.

Table 4-11 Summary of detailed assessment on dependencies for battery energy storage

Dependency	EU external dependence	Market concentration (CR4 Country)	Political risk	Ease of market entry	Availability of substitutes	Competitiveness trend
Raw Cobalt	>99%	72%	High	Low	Low	Not applicable
Refined Cobalt	32%	71%	Low	Low	Low	Not available
Battery Cells	High	95%	Low	Low	Medium	Stable

The main conclusions that can be drawn from this analysis are:

Raw cobalt is a critical dependency for the EU battery energy storage sector

The detailed assessment confirms the criticality of the dependency on raw cobalt that was suggested in the broad brush assessment. The EU is completely reliant on non-EU suppliers that are strongly concentrated in a few countries. The risk is heightened by the political risk associated with the main supplying country (Democratic Republic of the Congo) along with the difficulties to enter the market and the lack of suitable substitutes for the current battery technologies.

Refined cobalt is no critical dependency but maintaining the EU industry is of strategic importance

The detailed assessment showed that EU production capacities for refined cobalt are sufficient for meeting the EU demand. Finland and Belgium have considerable refining capacities, ranking 2nd and 6th globally. Hence, there is no critical dependency. Maintaining this strong position is of strategic importance for the EU battery energy storage industry, as the global market is relatively concentrated and substituting cobalt with other materials has substantial downside in terms of performance and safety.

Battery cells are a critical dependency but with a relatively low risk

The critical dependency for battery cells is confirmed through our detailed assessment, as the EU imports a large share of its consumption from a relatively concentrated market. However, the high market concentration ratio in terms of countries (95%) is somewhat misleading, since there are large capacities in the top 4 countries (China, Japan, South Korea and the US), all of which are politically stable. In conclusion, we consider the risk of this critical dependency relatively low.

4.6.1 Industry perspective on dependencies

The outcomes of this independent assessment of battery energy storage dependencies can be held against the viewpoints of industry on dependencies, which emerged during the interviews held in this study. The main viewpoints of the industry are:

The raw cobalt dependency is the main issue due to concerns about mining operations in the DRC

The main dependency of concern to the battery energy storage industry is raw cobalt. The industry is not necessarily concerned about an immediate shortage of supply but is mostly concerned about the sustainability and responsibility of the mining operations in the DRC. Some companies have implemented practices to mitigate these risks (e.g. Umicore's Sustainable Procurement Framework for Cobalt) while others invest in R&D for technologies that require less or no cobalt. But overall, the dependence on cobalt from the DRC remains one of the main risks for the sector.

The EU lags behind in battery cell manufacturing capacities and capabilities but has sufficient suppliers to choose from

The industry is not particularly concerned about the dependency on non-EU battery cell manufacturers. There are a sufficient number of suppliers to choose from and most are based in stable countries with which long-term trade relations exist, such as China, Japan, South Korea and the US. The current efforts to establish more production capacities in the EU do show that the EU lacks technical expertise for cell manufacturing, necessitating hiring of Japanese staff.

Battery recycling can become a strategic part of the value chain for the EU

Recycling can provide a domestic source of critical raw materials and is important for working towards a circular economy. Especially for the EU, it can become a strategic asset for mitigating dependency risks and for strengthening the domestic industry. However, building a competitive EU recycling industry that can deliver raw materials at competitive prices is not straightforward. End-of-life battery volumes in Asia are currently much larger than in the EU, leading to better opportunities for economies of scale in Asia. Part of the EU batteries are already shipped to Asia for recycling, even though there are sufficient recycling capacities and capabilities within the EU. On the other hand, recycling rates in the EU are larger than in other major economies and the interest in circular economy concepts is high. Overall, the EU battery energy storage industry considers battery recycling an area that should be a strategic priority for policy makers.

Breakthrough innovations may radically alter the dependencies

The industry expects to see breakthroughs in areas such as anode and cathode materials, solid state batteries and novel technologies for seasonal energy storage. Where these breakthroughs will come from and whether they will be patented effectively is a big question mark and may have a big influence on future dependencies and associated risks.

Annex A - List of interviewees

The following people were interviewed for this report:

Wind energy

Name	Organisation	Role
Tom Mansvelders	SIF	Commercial Manager New Markets
Aidan Cronin	Siemens Gamesa Renewable Energy	Advisory Specialist
Ward Gommeren	GE Renewable Energy	Managing Director
Rainer Broering	GE Renewable Energy	Executive Global Supply Chain Leader Wind Offshore
Dolf Elsevier van Griethuys	Van Oord	Business Development Manager
Ditlev Engel	DNV GL - Energy	CEO
Wilfried Breuer	TenneT	Managing Director / Member of Executive Board
Peter Charles Flower	DNV GL	Principal Engineer
Frank de Wild	DNV GL	Principal Consultant
Alessandro Panico	Prysmian Group	Sales Team Manager / Submarine and High Voltage Business Unit
Leo van der Pols	NKT	Business & Sales Development

Solar PV

Name	Organisation	Role
Radu Roman	Jinko Solar	Business Development Manager
Mathias Bremer	Wacker Chemie AG	Director Strategic Marketing
Ivar Blekastad	Norwegian Crystals	CCO
Michiel Mensink	Exasun	Director
Sanne Preso	Alliander	Consultant
Hans-Josef Fell	Energy Watch Group	Founder / President and former) Member of German Parliament
John Schermer	Radboud University	Head of department
Josefin Berg	IHS Markit	Research and Analysis Manager
Cormac Gilligan	IHS Markit	Research Manager
Oscar Charro	DNV GL	Consultant

Battery energy storage

Name	**Organisation**	**Role**
Peter van der Sluijs	Alliander	Strategy forecaster & strategic capability builder
David Merchin	Umicore	Emerging applications manager, rechargeable battery material
Guy Ethier	Umicore	Senior Vice President of Sustainability
Evert Raaijen	Alfen	Business development manager
Kevin Bradley	Bromine Council	Secretary General

Name	Organisation	Role
Thomas van Dijk	E-Stone Batteries	CEO & Business Development Manager
Hans van der Spek	Energy Storage NL Dutch Technology Industry Association – Energy Storage Platform	Program Manager
Bart Hoevenaars	Tesla	Sales Manager Powerpack
David Weight	cobalt Institute	President
Maurits Westerik	Birds & Birds	Energy lawyer
Bram Bonsen	EST Floattech	Technical director
Johan van Peperzeel	Van Peperzeel collection of industrial and consumer batteries	Managing director
Brittney Elzarei	EASE	Senior Policy Officer

Annex B - References

4C Offshore. (2018). *Global Market Overview Report - January 2018.* Lowestoft: 4C Offshore.

Ahonen, S. A. (2015). *Strengthening the European rare earths supply-chain: Challenges and policy options. A report by the European rare earths competency netowork (ERECON).* European Commission.

Benchmark Mineral Intelligence. (2018). *Cobalt & the rise of the lithium ion battery megafactories.*

Bhatt, M. D., & O'Dwyer, C. (2015). Recent progress in theoretical and computational investigations of Li-ion battery materials and electrolytes. *Physical Chemistry Chemical Physics*, 4799-4844.

BNEF. (2018). *Electric Vehicles.* Retrieved from Bloomberg New Energy Finance: https://about.bnef.com/electric-vehicle-outlook/#toc-download

Brumme, A. (2014). *Wind energy deployment and the relevance of rare earths: An economic analysis.* Wiesbaden: Springer Science & Business Media.

Busca, C., Teodorescu, R., Blaabjerg, F., Munk-Nielsen, S., Helle, L., Abeyasekera, T., & Rodriguez, P. (2011). An overview of the reliability prediction related aspects of high power IGBTs in wind power applications. *Microelectronics reliability*, 1903-1907.

Case M.8239 – NKT HOLDING A/S / ABB HIGH VOLTAGE CABLE BUSINESS, M.8239 (European Commission 02 27, 2017).

Castilloux, R. (2018). *Spotlight on Dysprosium - Revving up for rising demand.* Adamas Intelligence.

China Molybdenum. (2018). *2017 Annual Report.* Retrieved from China Molybdenum: http://www.chinamoly.com/06invest/DOC/2018/E_03993_04207.pdf

Choi, J. W., & Doron, A. (2016). Promise and reality of post-lithium-ion batteries with high energy densities. *Nature Reviews Materials*, 16013.

Circular Energy Storage. (2018). *The lithium-ion battery end-of-life market 2018-2025.* Circular Energy Storage.

Clean Energy Manufacturing Analysis Center. (2015). Benchmarks of Global Clean Enregy Manufacturing.

ClearViewIP. (2012). *Photovoltaics and IP - The Calm Before the Storm?* Retrieved from ClearViewIP: http://www.clearviewip.com/wp-content/uploads/2015/05/Photovoltaics.pdf

Cobalt Institute. (2018). Retrieved from https://www.cobaltinstitute.org/: https://www.cobaltinstitute.org/

Council of the European Union, European Parliament. (2006, September 26). Directive 2006/66/EC of the European Parliament and of the Council on Batteries and Accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC,.

CRU. (2018). *Technology Metals*. Retrieved from CRU: https://www.crugroup.com/analysis/technology-metals/

Deutsche Bank Markets Research. (2016). *Welcome to the Lithium-ion Age.*

Donald Chung, E. E. (2016). *Automotive Lithium-ion cell manufacturing: Regional Cost Structures and Supply Chain Considerations.* Golden, Colorado: CEMAC.

EAFO. (2018). *Vehicles stats*. Retrieved from European Alternative Fuels Observatory: http://www.eafo.eu/vehicle-statistics

Etacheri, V. M. (2011). Challenges in the development of advanced Li-ion batteries: a review. *Energy & Environmental Science*, 3243-3262.

EURARE. (2017). *Research and development for the Rare Earth Element supply chain in Europe.* British Geological Survey.

European Battery Alliance. (2018). *Internal Market, Industry, Entrepreneurship and SMEs*. Retrieved from European Commission: https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en

European Commission. (2016, July 12). Retrieved from European Commission SETIS: https://setis.ec.europa.eu/system/files/integrated_set-plan/action7_declaration_of_intent_0.pdf

European Commission. (2017). COMMISSION IMPLEMENTING REGULATION (EU) 2017/724 . *Journal of the European Union*.

European Commission. (2017). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions on the 2017 list of Critical Raw Materials for the EU.* Brussels.

European Commission. (2017). Communication on the 2017 list of Critical Raw Materials for the EU.

European Commission. (2017, 10 10). *http://madb.europa.eu/madb/statistical_form.htm*. Retrieved from Trade Market Database: http://madb.europa.eu/madb/statistical_form.htm

European Commission. (2018, August 27). *European Battery Alliance*. Retrieved from European Commission: https://ec.europa.eu/growth/industry/policy/european-battery-alliance_nl

European Commission. (2018, 8 31). http://trade.ec.europa.eu/doclib/press/index.cfm?id=1904.

Faure-Schuyer, A. (2018, April 27). *The European Battery Alliance: Ambitions and requirements.* Retrieved from CEPS: https://www.ceps.eu/publications/european-battery-alliance-ambitions-and-requirements

Financial Times. (2015). *China axes rare earths export quotas. Retrieved from Financial Times: https://www.ft.com/content/f0ec86fe-94b8-11e4-b32c-00144feabdc0.*

Fraunhofer ISE. (2018, June 18). *Photovoltaics Report.* Retrieved from Fraunhofer ISE: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

GEMC. (2018). *Cobalt Demand*. Retrieved from Global Energy Metals Corp: https://www.globalenergymetals.com/cobalt/cobalt-demand/

Glencore. (2018). *2017 Annual Report*. Retrieved from Glencore: http://www.glencore.com/investors/reports-results/2017-annual-report

GlobalData. (2017). *Global solar photovoltaic module shipments ranking.*

GTM Research. (2015). *Global PV Price Outlook 2015.*

GTMResearch inverter concentration. (2016, november). *www.greentechmedia.com/research*. Retrieved from https://www.greentechmedia.com/research/report/the-global-pv-inverter-and-mlpe-landscape-h2-2016#gs.SYxwX=A

Guyonnet, D. L. (2018). *Rare Earth Elements and High-Tech Products.* CEC4EUROPE.

IEA. (2018). *Global EV Outlook.*

IEA PVPS. (2018). *Trends in photovoltaic applications.*

IRENA. (2015). *Battery Storage for Renewables: Market Status and Technology Outlook.*

IRENA. (2017). *Electricity Storage and Renewables: Costs and Markets to 2030.* International Renewable Energy Agency.

JRC. (2013). *Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector.* Petten: JRC Scientific and Policy Reports.

JRC. (2016a). *Wind Energy Status Report.* Luxembourg: European Commission.

JRC. (2016b). *Lithium ion battery value chain and related opportunites for Europe.* European Union.

JRC. (2017). *EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications - Opportunities and Actions.* European Union.

JRC. (2018a). *PV Status Report 2018.*

JRC. (2018b). *Some considerations for EU industrial competitiveness and jobs in photvoltaic electricity generation.*

Kavlak, G., McNerney, J., & Trancik, J. (2018). Evaluating the causes of cost reduction in photovoltaic modules. *Energy Policy*, 123 (700-710).

Kotnis, J. (2018). *Critical raw materials in the city.* Delft: TU Delft.

Ladenberger, A., Arvanitidis, N., Jonsson, E., Arvidsson, R., Casanovas, S., & Lauri, L. (2018). *Identification and quantification of secondary CRM resources in Europe.* SCCREEN.

Marcelo Azevedo, N. C. (2018). *Lithium and Cobalt: A tale of two commodities.* Mckinsey&Company.

Mathieux, et al. (2017). *Critical Raw Materials and the Circular Economy - Background report.* JRC Science for policy report.

Melin, H. E. (2017). *Circular Opportunities in the Lithium-Ion Industry.* Circular Energy Storage.

Mishnaevsky, L. (2017). Materials for wind turbine blades: an overview.

Nationale Plattform Elektromobilität. (2016). *Roadmap integrierte Zell- und Batterieproduktion Deutschland.* Berlin: Nationale Plattform Elektromobilität.

New Energy Update. (2011). Electrical systems faults No. 1 cause of offshore wind turbine downtime. Retrieved from New Energy Update: http://newenergyupdate.com/wind-energy-update/electrical-systems-faults-no1-cause-offshore-turbine-downtime.

Olivetti, E. A. (2017). Lithium-ion battery supply chain considerations: analysis of potential bottlenecks in critical metals. *Joule*, 229-243.

Pavel, C. C. (2017). Substitution strategies for reducing the use of rare earths in wind turbines. *Resources Policy*, 349-357.

Pfrang Andreas, B. L. (2016). *Battery energy storage testing for safer, better batteries.* Retrieved from European Commission: https://ec.europa.eu/jrc/sites/jrcsh/files/battest_en_2016.pdf

Placke Tobias, K. R. (2017). Lithium ion, lithium metal, and alternative rechargeable battery technologies: the odyssey for high energy density. *Journal of Solid State Electrochemistry*, 1939-1964.

Powell, D. M. (2015). The capital intensity of photovoltaics manufacturing: barrier to scale and opportunity for innovation. *Energy & Environmental Science*, 3395-3408.

PV Magazine. (2017, December 11). *Canadian Solar next Chinese company to consider privatization*. Retrieved from PV-Magazine.com: https://www.pv-magazine.com/2017/12/11/canadian-solar-next-chinese-company-to-consider-privatization/

PV Magazine. (2018, March 30). *The weekend read: Cell manufacturer ranking*. Retrieved from PV Magazine: https://www.pv-magazine.com/2018/03/30/weekend-read-cell-manufacturer-ranking/

PVinsights. (2018, August 15). Retrieved from PVinsights: http://pvinsights.com/

PV-Tech. (2017, January 30). *Top-10 solar cell producers in 2016*. Retrieved from PV-Tech: https://www.pv-tech.org/editors-blog/top-10-solar-cell-producers-in-2016

PV-Tech. (2018, January 15). *Top 10 module suppliers in 2017*. Retrieved from PV-Tech: https://www.pv-tech.org/editors-blog/top-10-module-suppliers-in-2017

Rabe, W. K. (2017). China's supply of critical raw materials: Risks for Europe's solar and wind industries? *Energy Policy*, 692-699.

REN21. (2017). *Global Status Report.*

Roskill. (2018). *Lithium-ion Batteries - Market Development & Raw Materials.* Roskill.

Schulze, R. &. (2016). Estimates of global REE recycling potentials from NdFeB magnet material. *Resources, Conservation and Recycling*, 12-27.

SolarPower Europe. (2018). *Global Market Outlook.*

Somo. (2016). *Responsible Mining Cobalt.* GoodElectronics.

Spencer, E. (2016). Cobalt supply and demand. A global perspective. *The Cobalt Conference.* Seoul.

Statista. (2015, December 31). *Global annual refinery capacity of cobalt by top countries*. Retrieved from Statista: https://www.statista.com/statistics/339798/annual-cobalt-refinery-capacity-by-country/

Statista. (2017, September). *Global annual refinery capacity of cobalt by top countries 2015*. Retrieved from Statista: https://www.statista.com/statistics/339798/annual-cobalt-refinery-capacity-by-country/

Statista. (2017). *Study on the review of the list of Critical Raw Materials*. Retrieved from https://www.statistica.com/statistics/268790/countries-with-the-largest-lithium-reserves-worldwide/. [accessed 12 10 2017].

Statista. (2018, February). *Cobalt - mine production by major countries 2012-2017*. Retrieved from Statista: https://www.statista.com/statistics/264928/cobalt-mine-production-by-country/

Statista. (2018, June). *Lithium ion batteries - main manufacturers in Q1 2018*. Retrieved from Statista: https://www.statista.com/statistics/235323/lithium-batteries-top-manufacturers/

Taiyang News. (2017, January 10). *Trina Solar Starts Vietnam Factory*. Retrieved from Taiyang News: http://taiyangnews.info/business/trina-solar-starts-vietnam-factory/

Tan, L., Sun, H., Ye, X., Liu, Y., & Su, J. (2014). Comparing the Evolution of Cystalline Silicon Photovoltaic Cells: Technological Route and National Specialization. *Energy Procedia*, 1807-1811.

The Economist. (2012, November 21). *Sunny uplands - Alternative energy will no longer be alternative*. Retrieved from The economist: https://www.economist.com/news/2012/11/21/sunny-uplands

The Global Economy. (2018). *Political risk, long-term - country rankings*. Retrieved from The Global Economy: https://www.theglobaleconomy.com/rankings/political_risk_long_term/

Thomason, J. J. (2016). Glass fibre strength—A review with relation to composite recycling. *Fibers*, 18.

Trinomics. (2017). *Assessment of Photovoltaics.*

T-Solar. (2017, September 2017). *Perspectives of the photovoltaic (2017-2021). European market.* Retrieved from T-Solar: https://www.tsolar.com/en/news/perspectives-of-the-photovoltaic-2017-2021-european-market.html

Umicore. (2018). *Sustainable Procurement Framework for Cobalt.* Retrieved from Umicore: http://www.umicore.com/storage/main/sustainablecobaltsupplybrochurefinal.pdf

USGS. (2018a). *Mineral Commodity Summaries.*

USGS. (2018b). *USGS - Nickel Statistics and Information.* Retrieved from USGS - Minerals Information: https://minerals.usgs.gov/minerals/pubs/commodity/nickel/mcs-2018-nicke.pdf

USGS. (2018c). *USGS - Lithium Statistics and Information.* Retrieved from USGS: https://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2018-lithi.pdf

Vale. (2018, February 16). *Press Releases.* Retrieved from Vale: http://www.vale.com/EN/investors/information-market/Press-Releases/ReleaseDocuments/2017%204Q%20Production%20Report_i.pdf

WindEurope. (2017). *Wind in Power - 2016 European statistics.* Brussel: Wind Europe.

Zhou, B. L. (2017). Global potential of rare earth resources and rare earth demand from clean technologies. . *Minerals*, 203.

Annex C – Detailed assessment step-by-step manual

1 Introduction

This manual provides step-by-step instructions for undertaking part of the Energy Technology Dependence (ETD) assessment which has been developed for DG RTD under Framework Contract PP-02161-2014. The ETD assessment consists of two parts: a broad-brush assessment and a detailed assessment. This document is the detailed assessment step-by-step manual. The broad-brush assessment step-by-step manual can be found in *Task 3 report.*

The **aim** of the detailed assessment step-by-step manual is to standardise an in-depth analysis applicable to a selection of energy technology families/variants against indicators of critical dependency and other factors contributing to supply disruption.

The overall **objective** of the detailed assessment is to gain a deep understanding of the critical dependency issues, and other contributing factors, which create the conditions for potential threats to European energy technology interests, defined as:

- Increasing the cost of meeting European climate and energy objectives.
- Reducing productivity and employment in the European energy industry.
- Limiting the potential for European technology leadership.

The detailed assessment focuses on dependencies in the physical flow of goods and services including any element[14]. Dependencies on foreign knowledge are not considered explicitly in the detailed assessment.

The overall **tasks** of the detailed assessment are:

- <u>Review and validate the critical dependency elements</u> identified during the broad-brush assessment. This will be carried out during stage 1 and stage 2.
- <u>Identify additional critical dependency elements</u> through further literature review (stage 1) and systematic expert input (stage 2).
- <u>Carry out an in-depth analysis of critical dependency elements</u> against the two indicators of critical dependence, EU reliance on non-EU supply (stage 3.1) and market concentration (stage 3.2). Analysis will rely largely on quantitative sources.
- <u>Carry out additional analysis of critical dependency elements</u> focusing on other factors which contribute to the risk of supply disruption i.e. political and trade risk (stage 3.3), market entry barriers and availability of substitutes (stage 3.4) and competitiveness trends (stage 3.5).

The main tasks above apply to the energy technology families/variants selected for further analysis during the broad-brush assessment (see results in *Task 3 report*).

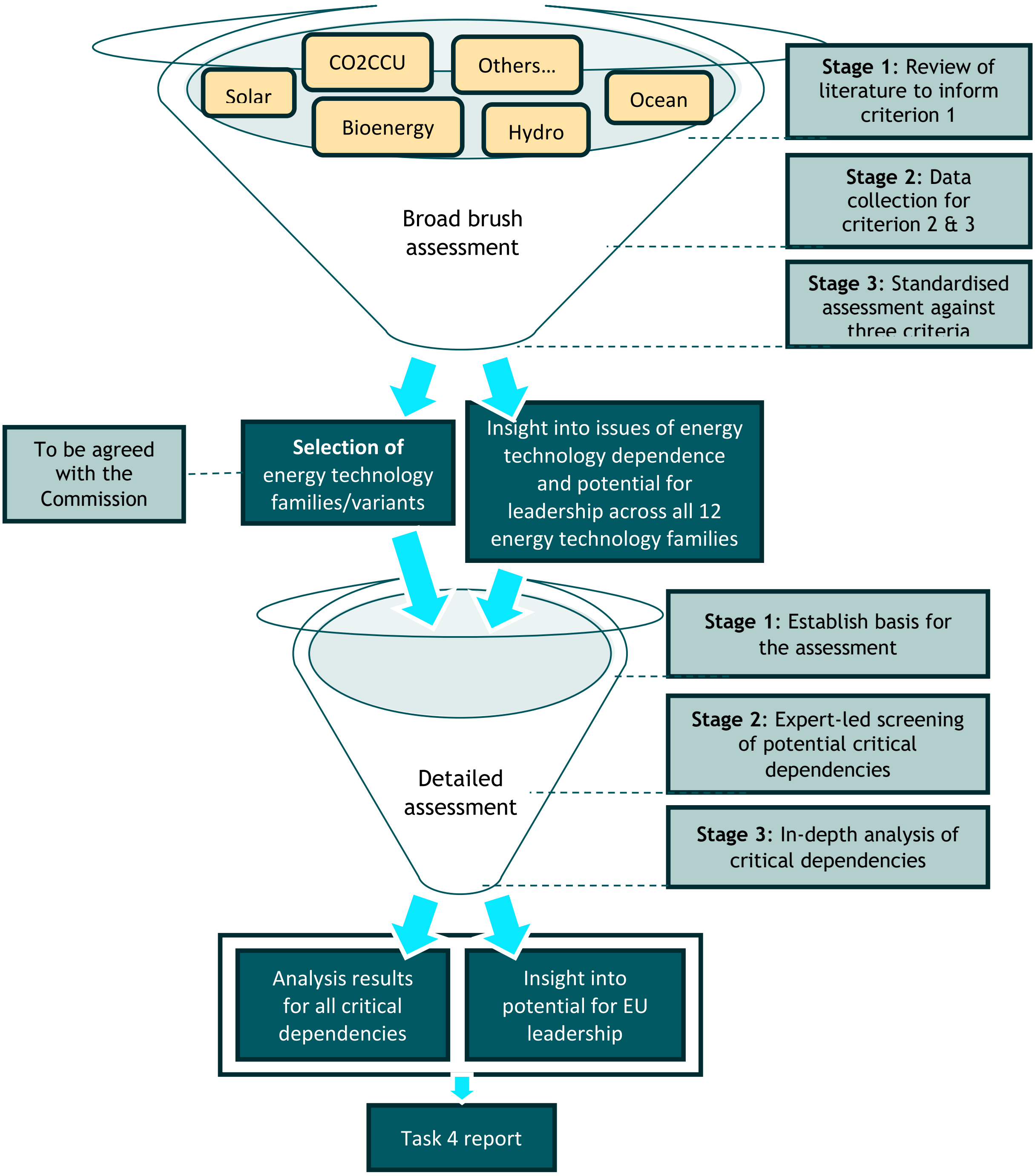
[14] "Element" is any raw material, component, sub-component, machinery, equipment, service, etc. which is part of an energy technology families/variants value chain.

The **outputs** of this analysis are detailed in the overview section of each stage in the report below. The outputs of this analysis will be used to develop a risk mitigation strategy (Task 5) and make policy recommendations (Task 6).

2 Overview of assessment process

The overall energy technology dependence assessment methodology is illustrated in Figure 7. Note that this includes both the broad-brush assessment and the detailed assessment.

Figure 7 Summary of energy technology dependence assessment methodolo



3 Detailed assessment

The detailed assessment is broken down into three stages (see details of key actions and outputs in Figure 8 below):

Stage 1: Establish the basis for the in-depth assessment
Stage 2: Expert-led screening of critical dependencies
Stage 3: In-depth data-based analysis of critical dependency elements

This step-by-step manual provides guidance on how to undertake the detailed assessment and outlines the methods and techniques that should be used and indicates potential sources of data that could be used to complete the assessment. Assessment templates for the detailed assessment are indicated in this document using *italics* with more detail provided in section 4.

Figure 8 Summary of detailed assessment methodology

	Summary of actions	Summary of outputs
Stage 1: Establish basis for the assessment	Stage 1.1 - Background research to further develop the list of potential critical dependency elements identified during the broad-brush assessment. Stage 1.2 - Collate and rank potential critical dependency elements against the two indicators of critical dependence, EU reliance on non-EU supply and market concentration.	A preliminary list of potential critical dependency elements (also referred as key elements) where each key element is scored against the two indicators of energy technology dependence, EU reliance on non-EU supply and market concentration. A literature review tracker recording all literature reviewed during stage 1.
Stage 2: Expert-led screening of critical dependency elements	Stage 2.1 - Survey/interview preparation and expert engagement with the aim of eliciting expert validation and identification of critical dependency elements. Stage 2.2 - Analysis of expert surveys/interview results with the aim of collating a comprehensive list of critical dependency elements and value chain maps. Stage 2.3 - Select key elements for analysis in stage 3 Stage 2.4 - Map technology value chain illustrating potential critical dependencies.	Comprehensive list of potential critical dependency elements (referred to as key elements) where each key element is scored by external experts against the two indicators, EU reliance on non-EU supply and market concentration. Value chain map for each energy technology family/variant which illustrates all potential critical dependency elements. Selection of key critical dependency elements to be analysed in stage 3.
Stage 3: In-depth data-based analysis of critical dependency elements	Stage 3.1 - Score each key element against external dependency indicator using selected measures and sources. Stage 3.2 - Score each key element against market concentration indicator using selected measures and sources. Stage 3.3 - Determine country specific risk for each key element for select countries using established indexes for political stability and trade. Stage 3.4 - Determine impact of market entry barriers and availability of substitutes for each key element using expert input. Stage 3.5 - Determine competitiveness trends for key elements where sufficient data is available	Comprehensive list of potential critical dependency elements assessed against critical dependency indicators and additional factors i.e. country specific risk, market entry barriers, availability of substitutes, and competitiveness trends. Value chain map for each energy technology family/variant which illustrates all potential critical dependency elements.

3.1 Stage 1 – Establish the basis for the in-depth assessment

Overview

The following actions will be carried out during stage 1:

- Stage 1.1 - Background research to further develop the list of potential critical dependency elements identified during the broad-brush assessment.
- Stage 1.2 – Collate and rank potential critical dependency elements against the two indicators of critical dependence, EU reliance on non-EU supply and market concentration.

The actions carried out in stage 1 will further develop the outputs from the broad-brush assessment and will focus only on the five energy technology families/variants selected during the broad brush assessment.

The outputs from stage 1 will be:

- A preliminary list of potential critical dependency elements (also referred as key elements) where each key element is scored against the two indicators of energy technology dependence, EU reliance on non-EU supply and market concentration.
- A literature review tracker recording all literature reviewed during stage 1.

The outputs from stage 1 will be validated and further developed during stage 2 (based on expert surveys and interviews) and will then be analysed in-depth during stage 3.

Stage 1.1 – Background research

The following actions will be carried out as part of stage 1.1:

- Identify gaps and areas where further research is required
- Carry out research to fill the gaps.

Identify gaps and areas where further research is required.

Start by reviewing the broad-brush summary papers and other ETD broad brush results (e.g. *literature source tracker)* with an aim to understand the quantity and quality of information found against the two indicators of energy technology dependence: reliance on non-EU supply and market concentration. Based on your expert view, the summary papers produced as part of the broad-brush assessment, and using the guidance provided in Table 12, determine what further research will need to be carried out, if any, as part of stage 1.1.

Table 12 Identifying gaps and areas where further research is required

Is further research required?	If yes, follow the suggested action.
For each key element (identified in the broad-brush assessment), is there insufficient information to score the key element in terms of non-EU supply and market concentration?	Carry out additional research on the key element where additional research is warranted. You may wish to refer to sources used during the broad-brush assessment. Expert interviews should also be carried out.
Are there any critical dependency elements which have not been identified? For example, has the entire value chain been assessed including raw materials, components, equipment and	Research potential issues and identify any additional critical dependency elements. Expert interviews should also be carried out.

Is further research required?	If yes, follow the suggested action.
services?	
Were there any specific suggestions or limitations highlighted in the broad-brush summary paper which warrant further research?	Carry out additional research. Expert interviews should also be carried out.

Keep in mind that there are too many elements related to modern energy technologies to assess all of their dependencies individually. However, we can anticipate that the majority of such elements will be commodity products or low risk products. The following will characterise the less relevant inputs:

- Where European suppliers have substantial market share or are net exporters.
- Where the global market is highly competitive with diverse suppliers from many countries.
- Where the input is typically not part of a globalised market and is likely to be sourced from within Europe.

It is worth being aware of the issue of indirect dependency which may emerge even though imported products are readily available to the EU, this is where foreign suppliers are exposed to risks in their own supply chains (e.g. foreign supplier of manufactured goods who is dependent on the supply of a raw materials). However, the existence of manufacturing equipment already installed in the EU, or a secondary market in the EU for used products, likely reduces the threat of the dependency.

Furthermore, it is expected that services requiring technical experts (e.g. manufacturing engineers) will not be a critical dependence element because it is relatively easy to develop in-Europe expertise in the case of a shortage. It is expected that most of the critical dependence elements will occur within the manufacturing and assembly stages of the value chains, including raw materials. Nevertheless, services will need to be considered as part of this assessment.

Carry out research to fill identified gaps.

The process of carrying out literature review can follow that set out in the broad-brush methodology Stage 1.1 literature review; it provides guidance on suggested search platforms and parameters and terms, as well as instructions on how to add each source to the tracker, score each source and determine whether or not there is sufficient coverage of the key topics. Any additional critical dependency elements identified during stage 1.1 will be collated in stage 1.2. Furthermore, ensure that additional sources are added to the source tracker.

Stage 1.2 – Collate and rank key elements

The following actions will be carried out as part of stage 1.2:

- Collate a list of key elements
- Score any additional key elements (identified in stage 1.1.) in terms of reliance on non-EU supply and market concentration
- Verify key element scores determined as part of the broad-brush assessment and amend these scores if necessary.

Collate a list of key elements identified during the broad-brush assessment and in stage 1.1 above into the *results table* (refer to section 4.1 for guidance on the *results table* template). Recall that an "element" is any raw material, component, sub-component, machinery, equipment, service, etc. which is part of an energy technology families/variants value chain.

Score each additional key element (identified in stage 1.1.) in terms of reliance on non-EU supply and market concentration, using expert judgement and by following the high, medium or low score guidance in Table 13. It is likely that exact numbers may not be known at this stage of the methodology - the expert should use the available information and their own judgement to make an assessment. The scores for each key element should be added to the *results table.*

Table 13 Preliminary scoring guidance

Indicators	Scoring guide		
	High	Medium	Low
Reliance on non-EU supply	High (e.g. > 70%) proportion of supply is imported.	Medium proportion of supply is imported.	Low (e.g. < 30%) proportion of supply is imported.
Market concentration	Element market is highly concentrated (less than 5 countries and less than 5 firms supplying the element to the global market).		Element market is highly competitive (greater than 10 countries and 10 firms supplying the element to the global market).

Verify key element scores for each element identified in the broad-brush assessment. Should there be any additional information found which supports changing this score, do so.

3.2 Stage 2 – Expert-led screening of critical dependency elements

Overview

In stage 2, external experts will validate and further develop the outputs of stage 1 (i.e. the preliminary list of critical dependency elements). External expert input will be gathered through surveys and interviews.

The following actions will be carried out during stage 2:

- Stage 2.1 – Survey/interview preparation and expert engagement with the aim of eliciting expert validation and identification of critical dependency elements.
- Stage 2.2 – Analysis of expert surveys/interview results with the aim of collating a comprehensive list of critical dependency elements and value chain maps.
- Stage 2.3 – Select key elements for analysis in stage 3.
- Stage 2.4 – Map technology value chain illustrating potential critical dependencies.

The outputs from stage 2 will be:

- Comprehensive list of potential critical dependency elements (referred to as key elements) where each key element is scored by external experts against the two indicators, EU reliance on non-EU supply and market concentration.
- Value chain map for each energy technology family/variant which illustrates all potential critical dependency elements.
- Selection of key critical dependency elements to be analysed in stage 3.

Stage 2.1 – Survey/interview preparation and expert engagement
This stage can either be executed through a survey or a series of interviews. The survey option is detailed in this methodology but can also be used as guidance for interviews if that approach is considered more appropriate.

The following actions will be carried out as part of stage 2.1:
- Modify the survey template for each energy technology family/variants
- Identify appropriate internal/external experts
- Engage selected internal/external experts

Modify the survey template to include specific references to the energy technology family/variant in question using the generic survey text provided in section 5.2. Save a Microsoft word version of the modified survey which will be circulated to interviewees. Typeform has been selected as the online survey platform for the ETD study. On Typeform, a generic version of the survey has been prepared and is accessible at https://admin.typeform.com/workspaces/8509575/#/. The online generic survey can be duplicated, on the Typeform website, and then tailored for each energy technology family using the text provided in section 5.2. It is important that only technology specific reference are tailored but all questions, scoring thresholds and general text should remain consistent across each of the energy technology family surveys.

Identify appropriate internal/external experts to provide input across all mandatory **survey objectives** below:
1. Verify outputs from stage 1 of the broad-brush assessment (i.e. list of key elements).
2. Provide recommendations on additional key elements which should be considered for this study.
3. Fill any knowledge gaps which were not understood during the broad-brush assessment and detailed assessment stage 1 (e.g. if there was limited or no literature which considered installation and maintenance concluding that there were no associated dependency concerns).

The type of experts needed will depend on the scope and specifics of input needed:
- Experts from trade associations, academics and consultants may be best suited for general input where a breadth of knowledge across the energy technology value chain, or large segment of the value chain, is beneficial.
- Experts whom purchase or supply the element being analysed may be best suited to provide specific input on that element, or where a more specialised understanding of dependency issues is beneficial. For example, manufacturers or buyers of a specific component will likely be best placed to comment on issues of dependence associated with the supply of the component (or sub-components) required to manufacture the component.

The number of experts needed will depend on a couple of factors, including their:

- Level of expertise.
- Willingness and availability to complete a survey.

As a guideline, it is expected that 10 completed surveys for each energy technology family/variant should be sufficient. The ratio of completed surveys to experts contacted will be highly dependent on existing relationships or prior knowledge of this project. As a guideline, response rates of 25% and 5% can be expected for existing contacts and cold contacts, respectively.

Engage selected internal/external experts following the engagement process guidelines in Table 14 and using the email template provided in section 4.3. The engagement process may be adapted to achieve the primary aim of eliciting a sufficient level of internal/expert input efficiently and effectively. In principle, the success of the engagement process will be enhanced by:

- Clearly and concisely communicating the purpose of the study.
- Outlining the benefit(s) of contribution.
- Directly requesting expert input and providing adequate instruction.
- Adopting a persistent, professional and polite approach to engagement.
- Agreeing/setting deadlines and following up as necessary.

Keep records of each stage of the engagement process including contact details, date of all emails and phone calls, and the final outcome (e.g. no response, completed survey, decline, and contribution). Please refer to the *detailed assessment interview tracker.*

Table 14 Engagement process guidance

Engagement process	Purpose	Resources (see section 4.3)	Tips/notes
First email (first contact)	Introduce the project. Request contribution. Articulate benefit of contribution.	First email template Study background (i.e. didactical material) Survey in pdf form	First email must be short, to the point, and persuasive.
Follow up phone call	Ensure the email is received and understood. Determine whether you have the best expert contact: ask for alternative contact if relevant. A follow up call will personalise the email request and give the opportunity to respond to any initial questions.		Follow up calls should be made ~24 hours after first email is sent; this gives some time to read, but not long enough that it is forgotten. Try to pin down dates by when the survey will be completed.
Second email (if necessary)	Chasing email, to be send if you do not receive a response		Best to keep this email very short: asking whether they

	to the first email and have not spoken over the phone.		have had a chance to consider involvement, and provide a 1-2 line summary of the first email. Include something that will catch their attention.
Follow up phone call	The last attempt.		Try to get a conclusive yes or no about whether they will participate.

Stage 2.2 – Analysis of expert surveys/interview results

The following actions will be carried out as part of stage 2.2:

- Collate survey results
- Determine whether survey objectives have been achieved
- Carry out additional survey (as necessary)
- Populate results table with survey/interview results.

Collate survey results and keep a record of all data provided. The survey results can be downloaded as an Excel spreadsheet from the Typeform website; this tabulates responses from each of the survey respondents.

Determine whether the survey objectives have been achieved, following the guidance in Table 15. Recall that the survey objectives are highlighted in stage 2.1. External expert input must be sought across the entire energy technology family/variant value chain - this is the final step in producing a comprehensive list of key critical dependencies.

Carry out additional surveys/interviews (as necessary). If the survey objectives have not been achieved (e.g. there is insufficient coverage of an energy technology family/variant value chain), additional experts will need to be surveyed (stage 2.1) and/or experts will need to be interviewed (stage 2.3). Note that coverage of respondents does not need to be even across each of these categories given that critical dependency elements are most likely to be associated with the manufacturing stage, however there should be some coverage of other stages to ensure that any critical dependency elements in these areas have not been overlooked.

Table 15 Guidance on determining sufficient coverage of survey objectives

Survey objective	Sufficient coverage if…
Verify outputs from stage 1 of the broad-brush assessment (i.e. list of key elements).	Primary requirement: Collective experience expert surveys must cover the entire energy technology value chain. For sections of the value chain where only one expert has provided input, their input should be provided with a high level of certainty. Guidance note: Knowledge of experts should ideally cover EU countries where the energy technology value chain is expected to be most prevalent.
Provide recommendations on additional key elements which should be considered for this	Primary requirement: Collective experience of experts who have completed surveys covers the entire energy technology value chain. For sections of the value chain

study.	where only one expert has provided input, their input should be provided with a high level of certainly.
Fill any knowledge gaps which were not understood during the broad-brush assessment and detailed assessment stage 1.	Primary requirement: Experts must be consulted to fill any knowledge gaps across the value chain. For sections of the value chain where only one expert has provided input, their input should be provided with a high level of certainty. Otherwise, additional surveys and/or interviews will be necessary.

Populate results table with survey results. Add any additional key elements, which were not identified in stage 1 or in the broad-brush assessment, to the *results table*. Add scores for each key element against the two indicators, extent of external dependency and extent of market concentration, to the *results table*. Also include certainty scores provided. Where key element scores vary across surveys a simple weighted average (accounting for score and certainty) should be used to determine the key element score. The expert may wish to speak with the external expert to further discuss the scores provided in the survey. Notes explaining reasoning for final scores, where relevant, should be retained.

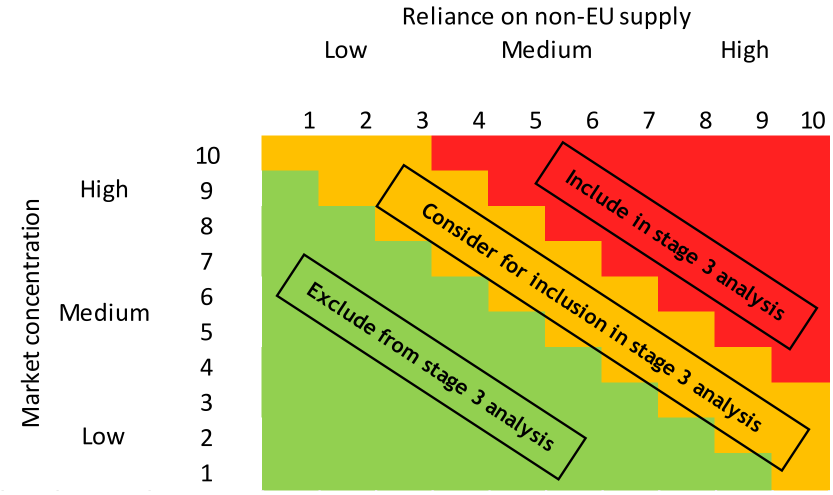
Stage 2.3 – Select key elements for further analysis and update results

Select key elements to proceed for further analysis in stage 3 following the guidance provided in Figure 9. Key elements with scores falling in the highlighted red section (Figure 9) should be further assessed following stage 3 guidelines. The inclusion of key elements with scores following in the highlighted amber section (Figure 9) should be considered for inclusion in stage 3 analysis if they meet one of the following:

1. The score for the key element has been given a medium to low certainty (this is a survey result).
2. EU reliance on the element, and/or market concentration, is likely to be susceptible to unexpected changes or expected to increase in the near future.
3. Further analysis of the element would be beneficial.

Elements with scores falling in the highlighted green section (Figure 9) do not required further analysis: the scores provided by experts in stage 1 and/or by external experts in stage 2 are deemed to be sufficient.

Figure 9 Guidelines for selecting key elements to proceed to stage 3 analysis



Stage 2.4 – Map technology value chain

The following actions will be carried out as part of stage 2.4:

- Create a value chain map for each energy technology family/variant.

- Assign each key element to its respective value chain map and write a brief description of each potential critical dependency.

Create a value chain map for each energy technology family/variant using a top-down approach. Each value chain map should only provide necessary detail: show the top-down connection to elements identified as critical dependencies (as per stage 2.3) and illustrate sections of the value chain map where issues of technology dependence are anticipated (e.g. manufacturing). Each bespoke value chain map should be created using existing sources/literature wherever possible.

The main purpose of the value chain map will be to aid the consideration of key elements across the value chain of each energy technology family/variant, and to communicate the final results of the ETD assessment.

The first tier of the value chain map should present the project lifecycle activities similar to that illustrated in section 4.4. In the second and third tier consider the suggested categorisation provided in Table 16. Remember, detail should only be provided where necessary: it may be adequate to only present tier 1 detail where issues of dependence are unlikely e.g. for research & design and distribution. On the other hand, some sections of the value chain (e.g. manufacturing) may need to be broken-down into multiple tiers to adequately present sections of the value chain where a variety of key elements are expected. In this case, it may be appropriate to have a segment of a value chain (e.g. manufacturing) covered in a second illustration and linked to the main value chain map. The expert should ensure that the value chain map is clear and not over congested. The value chain maps will not cover every element of the value chain but will focus on areas where critical dependencies are expected to arise (e.g. a specific manufacturing equipment, sub-components, etc.).

Table 16 Suggested categorisation for value chain mapping

Tier	Element type	Examples	Guidelines
1	Project lifecycle activities	Inputs; production, distribution, operation, etc.	For tier 1, include the full technology lifecycle, from conception to operation to final disposal. This is likely to be similar across energy technology families including: inputs, production, distribution, operation and maintenance, and recycling/reuse of the technology components after use.
2	Sub systems or components and services	Solar panel; recycling of used components.	Breakdown each tier 1 element as appropriate. Keep in mind where potential issues of EU dependence may arise – focus on these elements and avoid adding less relevant elements.
≥3	Sub-components, processes and equipment, and sub-services	Solar cell; silicon; wafer sawing.	Only breakdown tier 2 elements if proposed level 3 element: • Has been identified as a key element • Will further branch (e.g. tier 4) to a key element • If there is a view that it may need to be further considered (i.e. potential for dependency issues)

There are two basic routes to EU procurement of an element. These routes should be considered to determine whether an additional tier on the value chain is necessary for the element being considered. Take generator sets for example, where two basic procurement options should be assessed for potential critical dependence issues: importing generator sets from a non-EU manufacturer or manufacturing the generator sets in the EU. In the first option, where generator sets are imported, the assessment will focus simply on EU reliance on generator sets imported from non-EU countries and associated market concentration. In the second option, where generator sets are manufactured in the EU, the assessment will need to consider higher tier elements required to manufacture the generator sets (e.g. equipment, components, raw materials, services, etc.). This analytical approach should be used to determine the level of detail required in a value chain map.

Assign each key element to its respective value chain map. Key elements listed in the *results table* will be assigned to their respective element illustrated on the relevant energy technology family/variant value chain map. Refer to section 4.1 for guidance on the *results table* and section 4.4 for guidance on the value chain map. In addition, write a brief explanation of each key element to ensure that its position and function in the energy technology family/variant value chain is clear.

3.3 Stage 3 – In-depth data-based analysis of critical dependency elements

Overview

The following actions will be carried out during stage 3:

- Stage 3.1 – Score each key element against external dependency indicator using selected measures and sources.
- Stage 3.2 – Score each key element against market concentration indicator using selected measures and sources.
- Stage 3.3 – Determine country specific risk for each key element for select countries using established indexes for political stability and trade.
- Stage 3.4 – Determine impact of market entry barriers and availability of substitutes for each key element using expert input.
- Stage 3.5 – Determine competitiveness trends for key elements where sufficient data is available.

The outputs from stage 3 will be a:

- Comprehensive list of potential critical dependency elements assessed against critical dependency indicators and additional factors i.e. country specific risk, market entry barriers, availability of substitutes, and competitiveness indicators.
- Updated value chain map for each energy technology family/variant illustrating all potential critical dependency elements and providing an indication of the potential for supply disruption.

Stage 3.1 – Score each key element against external dependency indicator

The following actions will be carried out as part of stage 3.1:

- Determine the most appropriate measures and data sources to assess each key element against the EU external dependence indicator (indicator 1).
- Document the selected measures and sources.
- Calculate the final value for EU external dependence indicator.
- Clearly state key assumptions and document any calculations.
- Provide a certainty scoring reflecting the quality of measures and data sources.

In stage 3.1, the expert will determine appropriate measures (e.g. import volume of specific element in Euros), seek data and make assumptions to establish EU external dependence values for each of the key elements selected for further analysis in stage 2.3. Each of the key elements selected in stage 2.3 will be assessed against the EU external dependence indicator.

EU external dependence is the proposed indicator for EU reliance on non-EU supply (as defined in Figure 10).

Figure 10 : Defining EU external dependence indicator

$$EU\ external\ dependence\ (Indicator\ 1) = \frac{Value\ (volume)\ of\ element\ net\ imports\ into\ EU}{Value\ (volume)\ of\ EU\ apparent\ consumption\ for\ element} = \frac{x}{y}$$

Determine the most appropriate measures and data sources for determining a numerical value for the EU external dependence indicator in Figure 10, for each key element. The selection of measures and associated data sources should be considered in unison, determined using a flexible approach, and should be guided by the principles proposed in Figure 11 and considerations in Table 17. Selection of measures for "x" and "y", and associated data sources, will require balancing availability of data, quality of data, and the accuracy of the selected measures in estimating EU external dependence (indicator 1). Furthermore, consistency in approach across each of the key elements will need to be optimised. The use of assumptions may be required.

Figure 11 Guiding principles for selecting measures and associated data sources

Data sources should be:

- Credible
- Complete
- Current, and consistent dates across all elements being assessed
- Conveniently accessible/available
- Closely aligned with the "ideal" characteristics proposed in Table 17

Measures should be:

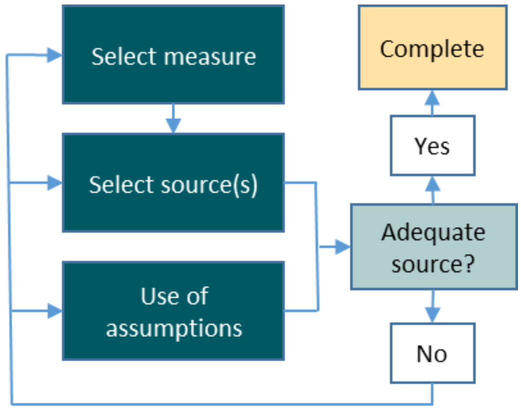
- Consistent across all elements
- Supported with credible assumptions as needed
- Closely aligned with the "ideal" characteristics proposed in Table 17

Table 17 Considerations when determining measures for EU external dependence indicator

Factors/Variables	Ideal	Key points
Time range	Most current annual data	Current data provides a better indication of the current situation.
Time range	Consistent date of data across elements	Consistency across elements is important for accurate comparison.
Volume or value	Present day value in euros	Data used should be consistent for each element, and ideally, consistent across all element. Conversions may be made clearly stating assumptions.
Measures for net imports	Element net import value from non-EU countries	For example, net import = import – export. Proxies may be considered where necessary.
Measure for demand	Element EU apparent consumption value	Proxies may be considered where necessary. For example, domestic production, import and export data could be used to approximate demand (i.e. apparent consumption = import – export + domestic production).

Figure 30 provides a suggested process for determining the optimal measure, source, and assumptions. Begin by selecting the ideal measure for "x" and "y" in Figure 10, and determine whether there are adequate sources for the selected measures. If sources are inadequate, consider use of assumptions, additional sources, or selection of an entirely new measure. This will likely be an iterative process and must be carried out to maximize achievement of the guiding principles in Figure 11. If a source is deemed inadequate first consider the use of assumptions, followed by selection of complimenting or separate sources, followed by selection of a different measure. Selecting a different (less ideal) measure should be the last resort in this iterative process.

Figure 30 Suggested general process for determining the optimal measures, sources, and assumptions



The most appropriate source(s) will depend on the measure and the key element. Figure 13 lists potential sources for each of the main element categories: raw material, component/equipment/machinery, and service/activity. Sources have been listed by order of preference where the top represents ideal sources and the bottom is a default to expert input provided during stage 2.

Figure 13 Guidance on selecting sources for different types of element

Raw material	Component / equipment / etc.	Service / activity
EU critical raw materials study	Trade and market statistics	Market statistics
Stage 2 survey/interview	Trade bodies	Market intelligence
Expert view	Market intelligence	Annual reports
	Annual reports	Industry contacts
	News articles	Stage 2 survey/interview
	Industry contacts	Expert view
	Stage 2 survey/interview	
	Expert view	

Document the selected measures and sources. State the selected measure in the *results table* and provide the reason why they were selected. All sources should be listed in the *detailed assessment source tracker* and referenced in the *results table*. This may be a combination of sources for a given element.

Calculate the final value for EU external dependence indicator (see Figure 10**)** for each element and enter it into the *results table*.

Clearly state key assumptions and document any calculations used, for each element, to determine the final numerical figure for indictor 1 in the *results table.* It is likely that assumptions will be required to account for limitations in data sources.

Provide a certainty scoring for the element's score against indicator 1 in the *results table* using the guidance in Figure 14. The certainty score provides an indication of the quality of the final value provided against indicator 1, a reflection of the extent to which this final value met the principles discussed earlier in this section. The certainty score should take into consideration the quality of the measure, quality of the source(s) used, quality of assumptions, and overall whether the data is a strong representation of the extent of EU external dependence of the element.

Figure 14 Guidance for scoring the certainty of final EU external dependence indicator value

Certainty score	With due consideration to the quality of measure, quality of sources, and quality of assumptions…
3 Stars (***)	…the final value is expected to be a **highly accurate** representation of EU external dependence on the element being considered.
2 Stars (**)	…the final value is expected to be a **moderately accurate** representation of EU external dependence on the element being considered.
1 Stars (*)	…the final value is expected to be of **limited accuracy** representation of EU external dependence on the element being considered.

Stage 3.2 – Score each key element against market concentration indicator

The following actions will be carried out as part of stage 3.2:

- Determine the most appropriate measures and data sources
- Document the selected measures and sources.
- Calculate the final value for the market concentration indicators
- Clearly state the key assumptions and any calculations
- Provide a certainty scoring reflecting the quality of measures and data sources.
- Determine whether further analysis is required
- Determine the firm or country share breakdown
- Determine which countries each of the CR4 firms have production facilities in

The Four-Firm Concentration Ratio (CR4) is the proposed indicator for the extent of supplier market concentration by firm and by country (as defined in Figure 15). Each of the key elements selected in stage 2.4 will be assessed against CR4-firm and CR4-country, which is the market share of the four largest firms and countries, respectively.

Figure 15 Defining market concentration indicators

The Four-Firm Concentration Ratio (CR4) is the market share of the four largest firms (or countries) and provides insight into the total output of an industry by a given number of large firms (or countries) in an industry.
CR4 firm and CR4-country are defined as follows:

$$\boldsymbol{CR4\ Firm} = global\ market\ share\ of\ the\ four\ largest\ firms\ supplying\ an\ element = A$$
$$\boldsymbol{CR4\ Country} = global\ market\ share\ of\ the\ four\ largest\ countries\ supplying\ an\ element = B$$

Where:

Largest country refers to the country where production capacity is located and thus exported from.

Global market includes all EU and non-EU countries and firms producing the element

EU countries are within one region, EU, and thus considered to be one entity for the purpose of CR4-country calculations

Definition of other variables may be adapted (see ***Error! Reference source not found.****)*

In stage 3.2, the expert will determine appropriate measures, seek data and make assumptions to establish CR4-firm and CR4-country values for each of the key elements identified in stage 2.4.

Determine the most appropriate measures and data sources for establishing numerical values for the market concentration indicators in Figure 15, for each key element. Similar to stage 3.1, the selection of measures and associated data sources should be considered in unison, determined using a flexible approach, and should be guided by the principles proposed in Figure 11 and considerations in Table 18. Selection of measures for "A" and "B", and associated data sources, will require balancing availability of data, quality of data, and the accuracy of market concentration measurement. Furthermore, consistency in approach across each of the key elements will need to be optimised. The use of assumptions may be required.

Table 18 Considerations when determining measures (market concentration indicator)

Variables	Ideal measure	Key points
Time range	Most current annual data	Current data provides a better indication of the current situation.
Time range	Consistent date of data across elements	Consistency across elements is important for accurate comparison.
Market share	Present day value in euros	Data used should be consistent for each element, and ideally, consistent across all element. Conversions may be made clearly stating assumptions.
Supply (CR4 – Firm)	% market share by firm	Where ranking of firms by market share is not available, or where the firms ranking is not exclusive to the element, use of available production data, sales data, etc. could be used (may require use of assumptions).
Supply (CR4 – country)	% market share by country	Where ranking of countries by market share is not available, or where the country's ranking is not exclusive to the element, use of available country export data, revenue figures, etc. could be used (may require use

Variables	Ideal measure	Key points
		of assumptions).

Figure 30 provides a suggested process for determining the optimal measure, source, and assumptions. Begin by selecting the ideal measure for "A" and "B" in Figure 15, and determine whether there are adequate sources for the selected measures. If sources are inadequate, consider using assumptions, additional sources, or selecting an entirely new measure. This will likely be an iterative process and must be carried out to maximize achievement of the guiding principles in Figure 11; where a source is deemed inadequate first consider the use of assumptions, followed by selection of complimenting or separate sources, followed by selection of a different (less ideal) measure. Selecting a different measure should be the last resort in this iterative process.

The most appropriate source(s) will depend on the measure and the element. Figure 13 lists potential sources for each of the main element categories: raw material, component/equipment/machinery, and service/activity. Sources have been listed by order of preference where the top represents ideal sources and the bottom is a default to expert input provided during stage 2.

Document the selected measures and sources. State the selected measure in the *results table* and provide the reason why they were selected. All sources should be listed in the *detailed assessment source tracker* and referenced in the *results table*. This may be a combination of sources for a given element.

Calculate the final value for market concentration indicators (see Figure 15**)** for each element and enter it into the *results table*. Remember that CR4 should be treated primarily as a comparative indicator, with higher scores indicative of greater market concentration.

Clearly state key assumptions and document any calculations used, for each element, to determine the final numerical figure for indicator 2 (Market Concentration) in the *detailed assessment results table.* It is likely that assumptions will be required to account for limitations in data sources.

Provide a certainty scoring for the element's score against indicator 2 in the results table using the guidance in Figure 16. The certainty score provides an indication of the quality of the final value provided against indicator 2. The certainty score should take into consideration the quality of the measure, quality of the source(s) used, quality of assumptions, and overall whether the data is a strong representation of the extent of market concentration relating to the element.

Figure 16 Guidance for scoring final data in terms of certainty (market concentration indicator)

Certainty score	With due consideration to the quality of measure, quality of sources, and quality of assumptions...
3 Stars (***)	...the final value is expected to be a **highly accurate** representation of market concentration for the element being considered.
2 Stars (**)	...the final value is expected to be a **moderately accurate** representation of market concentration for the element being considered.
1 Stars (*)	...the final value is expected to be a **limited accuracy** representation of market concentration for the element being considered.

Limitations of market concentration and identifying whether further analysis is necessary

CR4 ratios are a useful indicator of market concentration and provide a good level of insight into potential critical dependencies. However, CR4 ratios can overestimate the market power held by a group of suppliers as they do not account for factors like ease of market entry and potential for substitution. Each of the factors listed in Table 19 results in a decrease in the expected market power that a firm or country is likely to have in the market (specific to the element).

Table 19 – Key CR4 limitations, impact and solutions

Factors not accounted for in CR4 measure	Impact	Solution
CR4 ratio doesn't specifically state countries or firms	CR4 value provides no insight into EU role/leadership.	CR4 will be broken down by each of the four countries or firms.
Ease of entry	If barriers to entry are low, CR4 will overstate the market power of current suppliers.	Ease of entry will be assessed for critical dependencies in stage 3.4.
Competitive rivalry	Specific to CR4 firm, there can be tough competition between only 4 companies reducing the market power of an individual company.	CR4 firm will be broken down by each of the four firms.
Substitutes	Market power, and importance of critical dependence, is reduced where there are acceptable substitutes.	Potential for acceptable substitutes will be assessed for critical dependencies using expert insight in stage 3.4.
Foreign production	CR4-firm tends to overestimate the concentration of a domestic industry and underestimate the impact of foreign goods on competition.	This is accounted for by the use of CR4 country.
Elasticity of demand	Not considered in this assessment.	
Imprecise definitions	Not considered in this assessment.	
Coordinating economic activity	Not considered in this assessment.	

Determine whether further analysis is required for the key elements identified in stage 3.1 and stage 3.2 by following the decision guidance below:

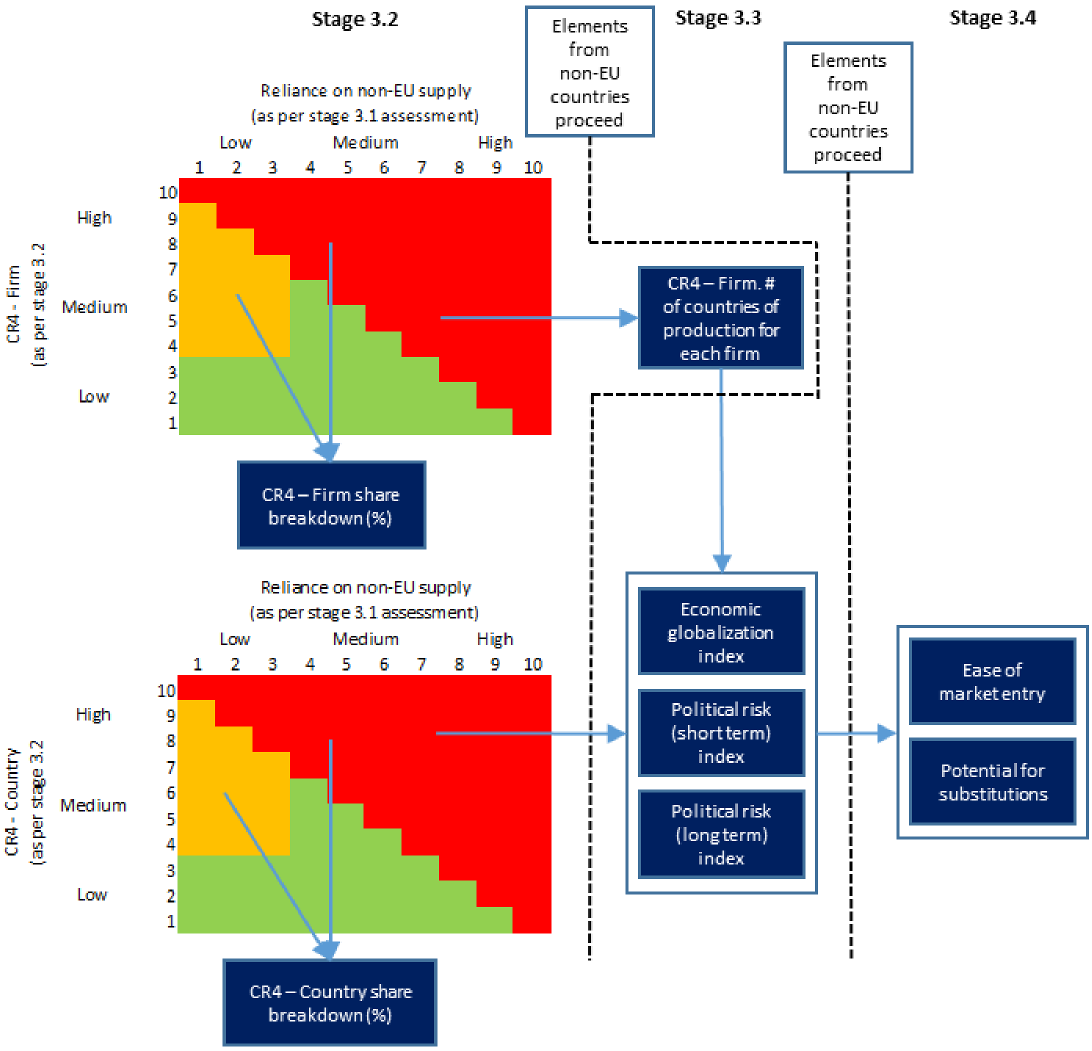
- Key elements which fall into the green highlighted section in Figure 17 do not require any further assessment.
- Key elements which fall into the orange highlighted section in Figure 17 will proceed through the remainder of stage 3.2, but do not require any further analysis in stage 3.3 or stage 3.4.

- Key elements which fall in the red highlighted section in Figure 17 will proceed through the remainder of stage 3.2 and will be further assessed in stage 3.3 and 3.4.

For key elements which fall into the orange and red highlighted section in Figure 17, **determine the firm or country share breakdown** which will be used to carry out further analysis, and also provides insight into the EU's role in highly concentrated markets and potential for EU leadership, if any, in the top four firms or countries. Populate the *results table* accordingly.

For CR4-firm, for key elements which fall into the red highlighted section in Figure 17, **determine which countries each of the CR4 firms have production facilities in.** Populate the *results table* accordingly.

Figure 17 Identifying if further information if required for a key element



Stage 3.3 – Determine country/political specific risk for each key element

The following actions will be carried out as part of stage 3.3:

- Gather the most recent political risk index (long term) data (Figure 17) for each of the non-EU CR4 countries.

It will be sufficient for one person to carry out this analysis.

The Political Risk Index is proposed as an indicator for risk of supply disruption from the country due to political issues, providing additional insight into supply risk of key elements identified as critical dependencies at the end of stage 3.2. Summary of the indicator is provided in Figure 18.

Figure 18 Suggested indicator of political risk - political risk index

Political risk index (long term):

- Definition: Political risk related to export transactions with a credit period of more than two years. Political risk covers the risks of foreign exchange shortages, wars, revolutions, natural disasters and arbitrary government actions.
- Source: Credendo Group and available on theglobaleconomy.com
- Countries are classified into seven categories (from 1-low risk to 7-high risk) reflecting the intensity of political risk.
- Source link: http://www.theglobaleconomy.com/rankings/political_risk_long_term/

Considering only key elements that fall into the red highlighted section of Figure 17, **gather the most recent political risk index (long term) data (Figure 18) for each of the non-EU CR4 countries** using the colour coding guidance in Figure 19. Index data for all countries can be found in the link provided in Figure 18 above. Save copies of all raw data sets and analysis of country risk. Input the final results into the *results table* as appropriate.

Figure 19 Three point scoring guide for economic and political indexes

Index	**Scale**	Low risk	Medium risk	High risk
Political risk index (long term)	(1-7)	1 – 2	3 – 5	6 - 7

Note, that there may be other suitable indicators of trade and political risks that could be considered and incorporated into the final results to provide further insight into the risk of supply disruptions from any country which the EU relies on for an element identified as a critical dependency in stage 3.2.

Stage 3.4 – Determine impact of market entry barriers and availability of substitutes for each key element

The following actions will be carried out as part of stage 3.4:

- Score each key element against each factor of ease of market entry
- Determine the final score for each key element on ease of market entry
- Score each key element against each factor of appropriate substitution
- Determine the final score for each element on the level of appropriate substitution

Ease of market entry and potential for appropriate substitutes are proposed as supplementary indicators for assessing the short/medium term risk of supply disruption, providing additional insight into the supply disruption of key elements identified as critical dependencies at the end of stage 3.2.

Ease of market entry

Although CR4 ratios are a useful measure of market power (see stage 3.2), they discount the effect of market entry barriers on the likelihood that companies, or countries, will maintain market power overtime. For example, consider a market completely dominated by four companies; the ability of those four companies to maintain market power over time is influenced by the ability of new market entrants to gain market share. The ease of market entry indicator enhances our understanding of the extent of market power in a concentrated market, and thus the risk of supply disruption of a critical dependence element.

Score each key element against each factor of ease of market entry as listed in in Table 20. Scores should be on a three-point scale. Scoring will be informed by existing literature and analysis, and ultimately on the expert's judgement. In the absence of credible literature and analysis, seek the professional opinion of industry experts (e.g. manufacturer of wind turbine generator sets). Make record of all references in the *literature review tracker.*

Determine the final score for each key element by summing scores against each factor of ease of market entry. This should be done on a three-point scale (i.e. high, medium and low) where each factor of ease of market entry is equally weighted. Again, the expert should use their judgement when determining the final score.

Table 20 Factors contributing to ease of market entry

Factors	Guidance on scoring (High, medium, low)
Start-up capital requirements	<u>High</u> start-up capital requirements; <u>low</u> ease of market entry.
High fixed costs	<u>High</u> fixed costs; <u>low</u> ease of market entry.
Entry protection (patents, rights, etc.)	<u>High</u> entry protection; <u>low</u> ease of market entry.
Economies of scale	<u>High</u> benefit from economies of scale; <u>low</u> ease of market entry.
Learning curve advantages (or "experience curve)	<u>Challenging</u> learning curve; <u>low</u> ease of market entry.
Access to distribution	<u>Complex</u> requirements for effective distribution; <u>low</u> ease of market entry.

Potential for substitution

Further analysis of the critical dependencies is required to take account of mitigating factors such as the availability of substitutes. The availability of adequate substitutes is central to the ultimate judgement on supply risk of a critical dependence overtime. Readily available and reasonable cost substitutes reduce the market power of suppliers and moderate the threat. Where the substitute products are homogenous then they effectively form a single large market with additional supplier diversity. In practice the impact of a substitute will depend on how homogenous it is. Even where currently available and reasonable cost substitutes are available, they are unlikely to fully resolve the threat from dependency.

Two distinct types of substitute can be anticipated:

1. Existing substitutes that are commercially available and potentially already in use in the market.
2. Potential future substitutes under development.

Score each key element against each factor of appropriate substitution as listed in Table 21. Scores should be on a three-point scale. Scoring will be informed by existing literature and analysis, and ultimately on the expert's judgement. In the absence of credible literature and analysis, seek the professional opinion of industry experts (e.g. manufacturer of wind turbine generator sets). Make record of all references in the *literature review tracker.*

Determine the final score for each element by summing scores against each factor of appropriate substitution. This should be done on a three-point scale (i.e. high, medium and low) where each factor of ease of market entry is equally weighted. Again, the expert should use their judgement when determining the final score.

Table 21 Factors to the appropriateness of substitution.

Factors	Guidance on scoring
Availability of direct substitutes.	No direct substitutes available; low potential for adequate substitution.
Technology readiness level (or commercial readiness level) of substitute	TRL of 6 or less; low potential for adequate substitution.
Homogeneity with the currently used element.	Homogeneous with the currently used element; high potential for adequate substitution.
Price differential	High price differential; low potential for adequate substitution.
Practical barriers to substitution	Significant practical barriers to substitution; low potential for adequate substitution.
Complexity of distribution	Distribution is complex; low potential for adequate substitution.

Stage 3.5 – Determine competitiveness trends for key elements

The following actions will be carried out as part of stage 3.5:

- Assess data availability on competitiveness indicators for key elements
- Fill data gaps with expert input
- Highlight trends in EU competitiveness for key elements

An analysis of trends on common competitiveness indicators is proposed as an additional insight into the evolution of critical dependencies. In case EU companies consistently lose market share over time, current dependencies can be expected to become worse over time resulting in an increased risk of supply disruptions.

Assess data availability on competitiveness indicators

As a first step, the availability of data on the most commonly reported competitiveness indicators needs to be assessed. The following indicators are proposed:

- Import, export and net import values: An increase in imports and/or decrease in exports over time, may indicate a lack of competitiveness of the EU industry;
- Jobs: A decrease in jobs in the EU industry may signal a lack of competitiveness;
- Turnover: A decrease in industry turnover may signal a lack of competitiveness.

The above indicators are proposed because the most data is expected to be available on these indicators. For each key element, the availability of sufficiently granular data on these indicators will be assessed. Subsequently, the best indicator will be selected for the technology.

Fill data gaps with expert input

Once the availability of data has been assessed, it will become clear for which key elements data is missing. For these elements, expert inputs will be collected to approximate trends on the selected competitiveness indicators.

Highlight trends in EU competitiveness for key elements

For each key element, the trend in EU competitiveness will be analysed. If data permits, a time series will be plotted (e.g. to show the evolution of the number of jobs over time). Otherwise, a qualitative description of the trends observed by experts will be provided.

Based on these inputs, conclusions will be drawn on the historical trend of EU competitiveness for the key element, roughly separating the following cases:

1. Strong competitiveness: EU industry shows consistent growth, pointing to a reduction in dependency over time.
2. Medium competitiveness: EU industry alternates between growth and decline, pointing to a relatively stable but uncertain view on the evolution of dependencies over time.
3. Low competitiveness: EU industry shows a consistent decline, pointing to a lack of competitiveness and growing dependencies over time.

These high-level cases will be supported with a qualitative discussion on the observed trend, incorporating any explanations provided by the experts.

4 Templates and guidance documents

4.1 Detailed assessment results table

See spreadsheet attached.

4.2 Online survey

Required modifications to survey template

As discussed in stage 2.1, the generic survey can be accessed at https://admin.typeform.com/workspaces/8509575/#/

Table 22 highlights questions where the text will need modifying to include the relevant energy technology family that the survey is being constructed for, and one question where a relevant example will need to be constructed for the survey.

Table 22 Alterations to be made to generic survey before issuing

No.	Part to be altered	Text to be altered ***(highlighted in yellow)***
Places where energy technology name to be added		
2	**description**	Please indicate which parts of the ***[energy technology]*** value chain you have a good understanding of.
3	**description**	A copy of the value chain map for ***[energy technology]*** was attached to the email we sent you.
4	**question**	In your view, which type of goods, components, inputs or services are the most important technology dependencies for ***[energy technology]*** in Europe?
4a, 4d, 4g 4j 4m	**description**	In your view, which goods, services, components or inputs are the most important technology dependencies for ***[energy technology]*** **in Europe?**
Places where example to be made relevant to technology		
4b 4e 4h 4k 4n	**description**	Please refer to the value chain map that was included in the covering email and enter the name or reference number of the box associated with the dependency you indicated. For sub-components of materials indicate the box on the map that contains the component or assembly of components that is relevant. ***For example, rare earth elements used in a generator's permanent magnets would be referenced as generator***

Example questions for offshore wind

The following example questionnaire has been developed for offshore wind.

Questions in the survey are shown below in bold. Other text provides further descriptions or instructions or choices for answers
1 Please tell us a little about yourself Your personal information will be kept private and will only be used for tracking survey results. a. **What is your name?** b. **Which organization are you representing?** c. **What is your position?** d. **What is your email address?**
2 Your area of expertise **Please indicate which parts of the offshore wind value chain you have a good understanding of.** a. **Value chain steps** **Please select all of the value chain steps below which you are familiar with. If 'Other' then please specify:** ☐ Research & development ☐ Planning & permitting ☐ Design ☐ Manufacturing (blades) ☐ Manufacturing (Other components) ☐ Installation ☐ Operation ☐ Decommissioning ☐ Other b. **Countries of expertise** **In which countries is your value chain expertise most relevant?** Please list one or more Member States or indicate that your experience is EU-wide or outside the EU.
3 Is the value chain map accurate? A copy of the value chain map for offshore wind was attached to the email we sent you. This provides an overview of the supply chain. Less detail has been included for value chain stages where technology dependence is considered less likely. For value chain stages where technology dependence is considered more likely, the main groups of components have been shown. **Please review the map and indicate below whether you feel it gives an accurate and comprehensive overview of the value chain.**
Thank you. We will now ask you to suggest potential dependencies. Please make sure you have carefully read the description of dependency included in the covering email and understand how we are measuring critical dependency. More information is available in the detailed background document that was attached to

your covering email.

4 In your view, which type of goods, components, inputs or services are the most important technology dependencies for offshore wind in Europe?

You can list up to 5 potential dependencies.

You will then be asked a few short follow-up questions.

It is likely that these dependencies will be at a more detailed component/sub-component/material level than is shown in the value chain map

Potential dependency 1 *

a. **Where is this good, component, input or service, located on the value chain map? ***

Please refer to the value chain map that was included in the covering email and enter the name or reference number of the box associated with the dependency you indicated.

For example, rare earth elements used in a generator's permanent magnets would be referenced as generator.

b. Would you like to add another? *

○ Yes ○ No

[Note questions repeat if answer is yes, up to a maximum of 5 dependencies]

5 Please answer a few quick questions about technology dependency 1 *[Survey inserts technology dependency one as specified by respondent]*

Where are supplies for the European market produced? *

A reliance on imports is an indicator of dependency.

Please make an estimate using the sliding scale:

○ ○ ○ ● ○ ○ ○ ○ ○

1 2 3 4 5 6 7

Produced in Europe Importe

How sure are you about your answer?

☆ not very sure

☆☆ fairly sure

☆☆☆ very sure

What is the market share of the largest four firms? *

A reliance on only a few firms means the market is concentrated and could create opportunities to influence price and availability.

Please estimate the market share of the largest four supplying firms using the sliding scale:

○ ○ ○ ● ○ ○ ○ ○ ○

1 2 3 4 5 6 7

Low concentration: 0% market share High concentration

How sure are you about your answer?

☆ not very sure
☆☆ fairly sure
☆☆☆ very sure

What is the market share of the largest four countries? *

A reliance on production in only a few countries makes supply disruptions more likely and makes trade restrictions possible.

Please estimate the market share of the largest four supplying countries using the sliding scale:

○	○	◉	○	○	○	○	○	○
	1	2	3	4	5	6	7	

Low concentration: 0% market share High concentration: 100% market share

How sure are you about your answer?

☆ not very sure
☆☆ fairly sure
☆☆☆ very sure

Additional information

Please add additional details here if you wish, such as the nature of the dependency or why you consider the threat to be a priority.

Please include references to supporting evidence where possible. You will be able to upload any relevant files at the end of the survey.

[Questions repeat for each technology dependency identified]

6. If you would like to add any other technology dependencies or to provide any additional comments or queries, you can do so here:

7. You can upload any evidence here.

[Opportunity to upload up to five files; size limit of 10MB per file]

8. Thank you for taking part.

a. Would you be happy for us to contact you if we would like to discuss any of your answers in more detail

○ Yes ○ No

b. What is your phone number?

9 Finally, can you suggest other people who we should send this survey to?

4.3 Contacting experts for survey

Suggested email for accompanying survey

Dear Name:

As an expert in [energy technology], we would like to ask for your expert input to a study for DG RTD (Research and Innovation) of the European Commission on the energy technology dependence of low carbon technologies. Energy technology dependency assessments provide policy makers with insights into critical security concerns which could undermine the transition to a low carbon energy system. They also provide insights into the leadership of European industry. The study has defined a critical technology dependency as shown below:

A component that is imported into Europe from only a few firms or countries heightens the risk of a supply disruption and gives those suppliers market power which can be abused. It makes threats to limit availability or increase prices credible.

A **critical dependency** is therefore where supplies are imported from a highly concentrated market and represent a threat to European energy interests, including:

- Increasing the cost of meeting European climate and energy objectives
- Reducing productivity in the European energy industry
- Limiting the potential for European technology leadership

More information on the study and a more detailed explanation of critical dependency is given in the study overview appended to this email.

Initial research completed in the study has been used to draw a value chain map for [energy technology] (attached) and to identify the following elements as potential technology dependencies:

[INSERT Technology dependencies table from Stage 4, Step 1

We would like you complete a short on line survey to:

- Confirm whether these are potential technology dependencies
- Add any additional technology dependencies
- Provide supporting information which will help us to complete a detailed assessment of dependencies.

The survey asks you:

- For some information about yourself and your areas of expertise
- To comment on the value chain map which has been completed for the technology (attached) For stages in the value chain where no technology dependencies are anticipated e.g. quality assurance, the map has been completed in a less detailed way.
- To identify up to five key elements where you think a technology dependency may be likely
- For each of these potential dependencies to give you views on reliance on imports, the market share of the largest four firms and of the largest four supplying countries

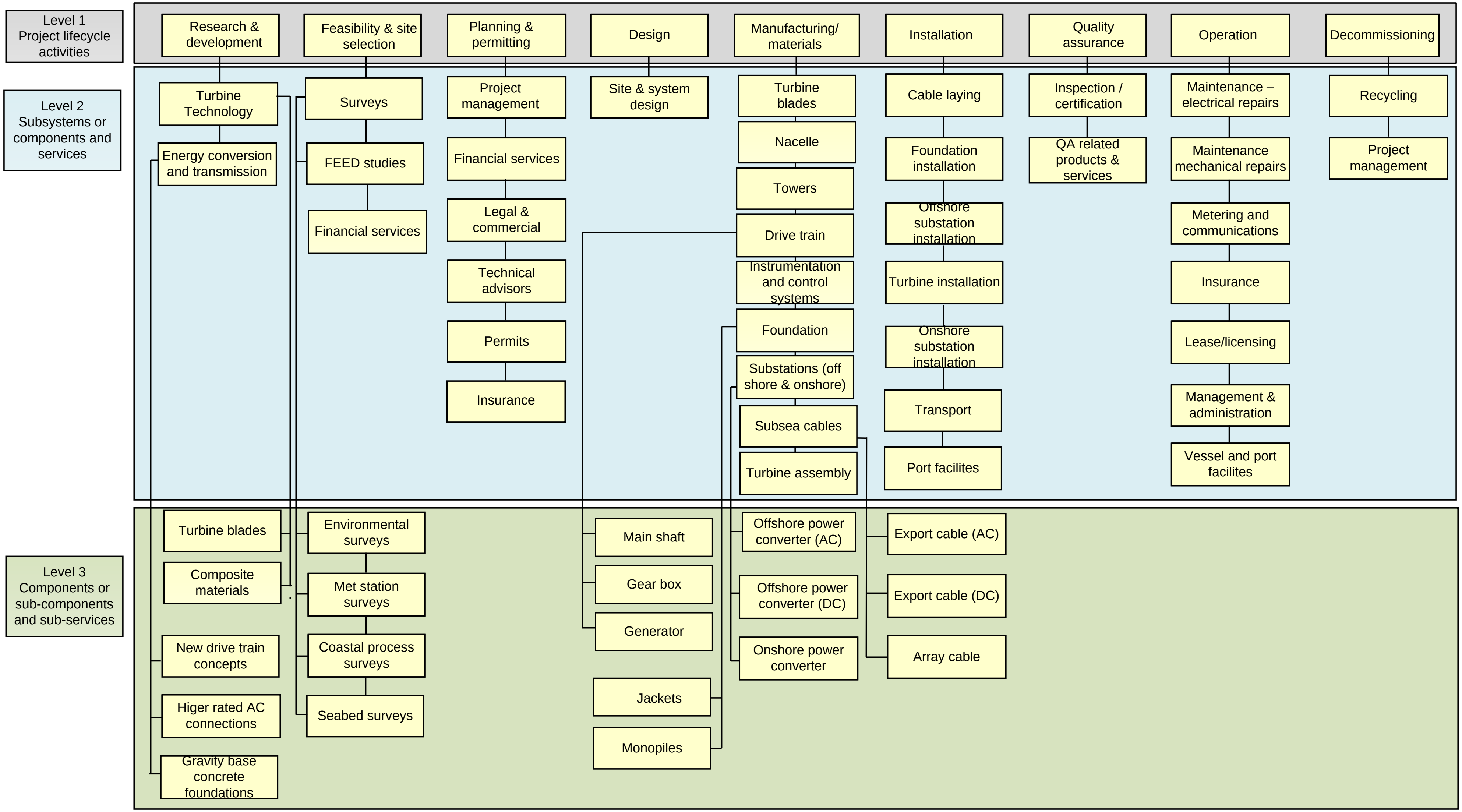
There is an opportunity for you to add additional information about the dependencies, give links to evidence and to upload files.

The survey is accessed at (Website reference for specific technology survey to be inserted)

We anticipate that it will not take more than an hour to complete. Please note that it is not possible to save the survey and then return to it to finish completing it or amend your answers, so you may wish to ensure you have anything you wish to refer to while completing it to hand. A full list of the questions is given in the attached survey document, if you wish to look at them before beginning the survey.
If you have any queries about the survey or the study, or would like to discuss any aspects of your response in more detail, then please feel free to contact me.

Thank you for your time.

4.4 Example of value chain map



5 Glossary of definitions

Definitions of key terms are given in the table below in alphabetical order. Relevant definitions have been taken from the “Appendix 5 – Glossary of definitions” submitted as part of the ETD interim report.

Critical dependence: where the extent of **dependence** is high and where the supply **market concentration** is high (i.e. in the hands of a few firms or countries) giving them market power and the ability to influence availability and price.
Critical Technology (also referred to as critical dependency element, or key element) is any technology (including equipment, skill, system, service, infrastructure, software or component) that is required by any organisation with a legal or contractual responsibility for security of citizens in Europe to properly perform its duties. (Burbiel & Schietke, 2013) Critical technologies, which cannot be provided by Europe independently, are defined as **Critical Dependencies.**
Criticality is analogous to dependency, where the criticality of materials is defined as those materials with the most acute combination of supply concerns combined with a high economic importance in Europe (Oakdene Hollins; Fraunhofer, 2013)
Dependence Issues can be defined as related to both physical unavailability and price increases.
Dependence (in the context of European energy technology dependency) is the reliance on an energy technology component, material, equipment, service, etc. that is primarily supplied from outside Europe.
Economic globalization: The inward and outward flow of goods, services, and investment across national borders, along with the functions —including functions related to innovation — that enterprises and organizations use to set up, support, and manage these flows. (Sturgeon, 2013)
Element: element refers to any element in the value chain of a product/service e.g. material, component, sub-component, equipment, service, etc.
Energy Security: Adequate supply of energy at a reasonable cost’ (IEA 1985). “A security of supply risk refers to a shortage in energy supply, either a relative shortage, i.e. a mismatch in supply and demand inducing price increases, or a partial or complete disruption of energy supplies” (Scheepers, Seebregts et al., 2006: p. 13) (Winzer, 2010)
Energy Technology Dependence: Reliance on an energy technology good, service, component or input that is primarily supplied from outside Europe. *A critical dependency* is defined as: Where the extent of the external dependence is high and where the supplier market is concentrated in the hands of few firms or countries, giving them market power and the ability to influence availability and price
External dependency: External dependency risk is the risk posed by reliance on other organizations with different strategies and stability. A program’s level of dependence on an external organization is one component of external risk. If a target/objective (e.g. space mission) cannot succeed without the external

organization, the mission is wholly dependent on it. If the external organization plays a part but achieving the target/objective is not reliant on it, then the risk to the target/objective is lower (Gerstein, et al., 2016).
Global value chain: Similar to value chain, however, a global value chain is divided among multiple firms and geographic spaces. The relationships among firms in GVCs varies based on a number of factors including product characteristics (i.e., number of components or weight of the product), firm capabilities, and the ability to standardize the production process. (Frederick, 2016)
Measures: There are a range of other established measures, used across a variety of studies, which have been considered as measures of EU dependency, and potential for substitutability.
Market concentration reflects the number and size distribution of firms in an industry. The market is more competitive when it is formed of many companies with low market share. When the market is dominated by only a few larger firms the market is concentrated which gives these firms market power. The EU Merger Regulations, the basis for competition policy at the European level, defines market power, or control as 'Conferring the possibility of exercising decisive influence over an undertaking[15]. Market concentration creates the conditions for the abuse of market power and the ability to restrict output and withhold supplies and thereby raise prices, and to reduce quality.
Non-dependence refers to the possibility for Europe to have free, unrestricted access to any required technology (European Commission , ESA, European Defence Agency, 2015)
Supply chain: A supply chain emphasizes the manufacturing and distribution-related steps. (Frederick, 2016))
Technology family
Technology family variant
Value chain. The value chain describes the full range of activities required to bring a product or service from conception through the different phases of production, delivery to final consumers, and final disposal after use. (Sturgeon, 2013) **Value chain.** The value chain describes the full range of activities that firms and workers do to bring a product/good or service from its conception to its end use and beyond. This includes activities such as design, production, marketing, distribution and support to the final consumer. A value chain can be contained within a single geographic location or even a single firm. (Frederick, 2016)
Value chain mapping: Value chain mapping is the process of identifying the geography and activities of stakeholders involved from taking a good or service from raw material to production and then to the consumer (input-output). (Frederick, 2016)

[15] https://www.slaughterandmay.com/media/64572/the-eu-merger-regulation.pdf

Getting in touch with the EU

IN PERSON
All over the European Union there are hundreds of Europe Direct information centres.
You can find the address of the centre nearest you at: https://europa.eu/european-union/contact_en

ON THE PHONE OR BY EMAIL
Europe Direct is a service that answers your questions about the European Union.
You can contact this service
– by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),
– at the following standard number: +32 22999696 or
– by email via: https://europa.eu/european-union/contact_en

Finding information about the EU

ONLINE
Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

EU PUBLICATIONS
You can download or order free and priced EU publications at: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en)

EU LAW AND RELATED DOCUMENTS
For access to legal information from the EU, including all EU law since 1952 in all the official language versions, go to EUR-Lex at: http://eur-lex.europa.eu

OPEN DATA FROM THE EU
The EU Open Data Portal (http://data.europa.eu/euodp/en) provides access to datasets from the EU. Data can be downloaded and reused for free, for both commercial and non-commercial purposes.

The overarching objective of this study was to better understand the dependence of the European Union on energy technologies and to specifically consider the impact of this dependence on the security of energy supply in the EU and on the EU objective of becoming a world leader in renewable energy technologies. The deliverables of this study include a set of relevant definitions on the concept of energy technology dependence (ETD), a methodology for assessing energy technology dependencies, a broad brush and detailed assessment of current energy technology dependencies, and policy recommendations for addressing such dependencies. This document includes the methodology for, and results of, the detailed assessment.

Studies and reports

Publications Office
of the European Union