Study on energy technology dependence

Mitigation Strategies and Policy Recommendations

Independent
Expert
Report

Stephan Slingerland, Federica Gerber, Onne Hoogland, Koen Rademaekers
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Research and Innovation

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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

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Report on Mitigation Strategies and Policy Recommendations

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2020 Secure, Clean and Efficient Energy

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Preface: Recommendations for EU research, innovation and competitiveness policies and programmes

This report has been delivered for the European Commission, DG RTD. This preface provides a summary of the recommended actions for EU research policy deriving from this report. The remainder of the report provides the full analysis that led to these recommendations.

D.1 Strategic action

Through Horizon Europe

- **Targeted RD&I on energy dependencies and upscaling of energy transformation**

Focus future Horizon Europe calls as well as SET Implementation plans on energy dependency RD&I in all value chain phases, particularly also on on-site integration, re-use and recycling, as well as on upscaling and EU industry development and employment aspects of innovations. Specifically

- Continue with RD&I directed at finding substitutes for raw materials and improving efficiencies of components and end-products;
- Step up investigation of re-use and recycling technologies as a contribution to a circular economy and to mitigating dependencies;
- Stimulate, next to fundamental RD&I on a low-TRL focusing on materials science, also RD&I on higher TRLs is required that focuses on on-site integration and installation;
- In all application-directed RD&I at higher TRLs, attention should be paid to employment aspects of technology that is developed as well as to the social aspects of a large-scale energy transition. This should preferably comprise high-tech as well as low-tech employment opportunities in order to foster employment opportunities for all Europeans.

Through EC policies

- Promote making a strategic and forward-looking energy technology dependence assessment as carried out in this study part of the already existing reporting obligations for the EU under the Better Regulation Guideline;
- Suggest promoting and branding ‘made in Europe’ low-carbon energy technology as part of a wider campaign to reinforce EU internal cohesion after Brexit;
- Discuss improving tailored clustering support and market differentiation per industry segment building on the examples of the European Battery Alliance and the Energy Technology & Innovation Platforms;
- Promote the development of open energy technology markets and multilateral trade agreements and addressing existing public resistance against these;

- Discuss transparency of resource flows and promoting environmentally and socially responsible mining inside and outside the EU as well as strategic assessment on an EU level of Member States' contingency planning for future energy dependency crises.

D.2 Specific action

Wind

- Expand EU RD&I for neodymium and dysprosium substitutes, most urgently for neodymium and possibly in cooperation with Japan and the US. This could be done in particular under the SET implementation plan wind offshore action 'materials science', next to general research stimulation options under Horizon2020 and Horizon Europe;
- Examine economically viable opportunities for small-quantity recycling of neodymium and dysprosium. This could be done in particular under the SET implementation plan wind offshore action 'industrialisation';
- Install separate expert groups on neodymium and dysprosium under the Raw Materials Initiative;
- **Investigate** general extension **possibilities** of lifetimes of wind turbines by dedicated RD&I in order to increase materials efficiency and reduce dependency risks.
- Stimulate the continued development of possible substitutes for XLPE such as EPR and P-laser. This could take place under Horizon 2020 and Horizon Europe programmes, as well as more specifically under the Wind Offshore SET implementation plan, actions 'system integration' and 'materials science'.
- **Stimulate** RD&I that can provide an alternative to fibreglass, in particular carbon, through a reinforcement of activities foreseen in SET plan and through general RD&I stimulation under Horizon2020 and Horizon Europe.

Solar PV

- Stimulate RD&I into tailored PV products in which design and aesthetics plays an important role next to price considerations in support for the EU PV cells and modules industry;
- Increase European RD&I on improved materials efficiency in solar cell and module technology, including perovskite and HIT options, in lower TRL levels and on building-integrated PV in the higher TRL levels;
- Foster PV recycling and design-for-recycle based on ongoing JRC research and through support for industry initiatives like PV-CYCLE;

Battery Energy Storage Technology

- Step up funding for the development of alternatives to the current use of cobalt in batteries;
- Stimulate RD&I for expanding the EU battery recycling industry;
- Improve the collaboration between the EU and other regions (e.g. the US) on sharing knowledge regarding mapping raw materials reserves.

1 Overview

1.1 Introduction

This report is the final part of the "Study on energy technology dependence" carried out for DG RTD under Framework Contract PP-02161-2014. The 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 Figure 1-1. From these definitions, it follows that a critical dependency comprises supply risks as well as risks to European energy innovation and EU industrial competitiveness. This integrated approach of energy security of supply and industrial competitiveness is a specific viewpoint of this project and an innovative approach compared to the previous practice to assess both policy areas separately.

Figure 1-1 Definition 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 energy industrial competitiveness policies[1].

Previous tasks that have been carried out in this project are (Figure 1-2):

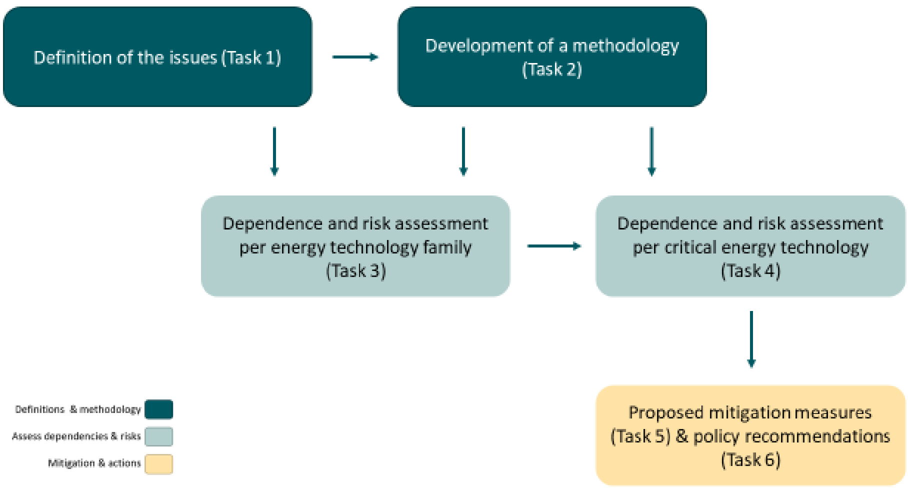
- A scoping study and definition of the issues at stake (Task 1);
- Development of a detailed methodology for assessment (Task 2);
- A 'broad brush' analysis of 21 possible low-carbon energy technology dependencies (Task 3);
- A detailed analysis of dependencies of three selected key low-carbon energy areas: wind, solar PV and battery energy storage (Task 4).

This report specifically covers Tasks 5 and 6 of the study: conclusions on possible mitigation actions needed and recommendations for action to DG RTD and other relevant stakeholders.

[1] EU industrial competitiveness in the field of energy is here seen as a leading position in innovation, development and commercial exploration of low-carbon energy technologies. Five indicators were selected to assess EU energy industrial competitiveness (see Table 1-2).

Thereby it will take into account the more general outcomes of Task 3, as well as the specific outcomes of Task 4.

Figure 1-2 Schematic project overview



1.2 Main results of previous project stages

In Task 1 of this project, key definitions for the terms 'dependency' and 'critical dependency' were explored and developed. These are summarized in Figure 1-2. Task 2 comprised the development of the methodology for this project, including didactical materials and a step-by-step manual. Essential steps in this methodology are a 'broad brush analysis' of a wide range of technology families (Task 3) and a 'detailed assessment' of some selected technologies (Task 4).

The broad-brush analysis carried out in Task 3 of the project consisted of three main stages:

1. **Identification of key critical dependency risks.** This analysis was carried out through detailed examination of 13 energy technology families with each several variants (Table 1-1).

Table 1-1 Technology families and variants considered in broad-brush analysis

Energy technology families considered	Variants considered
Bioenergy	Thermochemical conversion; Biochemical (including algae) conversion
CO2 capture	Pre-combustion capture; Post-combustion capture: Oxy-fuel combustion
CO2 storage	Depleted oil reservoirs; Depleted gas reservoirs and aquifers; Enhanced hydro carbon recovery
CO2 utilisation	Carbonate mineralization; CCU fuels
Energy storage	Compressed air energy storage (CAES); Flywheels; Li-ion batteries; Redox flow batteries; NaS batteries; Lead acid; Super caps; Hydrogen storage; Thermal Energy

Energy technology families considered	**Variants considered**
	Storage
Flexible conventional thermal power plants	Gas engine-based energy plants; Stationary gas turbine-based energy plants
Geothermal energy	High enthalpy: dry steam geothermal and flash steam geothermal; Low enthalpy: binary cycle geothermal plants
Hydropower	Run-of river hydropower plants; Reservoir hydropower plants; Pumped storage plants
Hydrogen & fuel cells	Renewable hydrogen (RH); Proton-Exchange Membrane Fuel Cells (PEMFC); Solid Oxide Fuel Cell (SOFC)
Ocean energy	Wave energy; Tidal energy
Solar energy	Photovoltaics (PV); Concentrated solar power (CSP); Solar heating and cooling
Wind energy	Offshore energy; Onshore energy
Heat pumps	Ground source; Air source

2. **Examination of the importance and impact of the critical dependency risks identified.** This investigation stage consisted of detailed analysis of two criteria for security of supply (i.e. current installed capacity in the EU and net capacity additions until 2030 in the EU) and five criteria for industrial competitiveness (i.e. current global installed capacity, global net capacity additions until 2030 , EU share of EPA patent applications, EU share of global patent families and EU share of global publications).

3. **Expert judgment on main technologies to be selected for detailed analysis.** In the final stage in the broad-brush, a team of experts judged the outcomes of stages 1 and 2 and made a final selection of energy technologies to be studied in detail in task 4. Wind energy, solar PV and battery energy storage were selected (Table 1-1).

Table 1-2 Results of broad-brush technology assessment (Task 3)

Broad brush assessment - Summary table	Criterion 1: Critical dependence	Criterion 2: Importance for EU security of supply		Criterion 3: Importance for EU leadership in renewables					Final selection for detailed assessment (Task 4)
	Extent of critical dependence**	Current installed capacity - EU	Net capacity additions until 2030 - EU	Current installed capacity - World	Net capacity additions until 2030 - World	EU share of EPA patent applications	EU share of global patent families	EU share of global publications	Expert assessment based on scores on criteria 1, 2 and 3
Technology family or variant*	High/medium/low	MW	MW	MW	MW	%		%	
Solar - Photovoltaic	Medium	100.414	49.436	290.791	658.426	35%	9%	25%	Firm
Solar - Concentrated solar power	Medium	2.308	2.569	4.873	29.376	59%	17%	38%	Secondary
Solar - Heating & cooling	Low	34.357	84.541	416.675	297.049		24%	31%	
Wind	High	154.283	116.974	466.505	652.622	69%	29%	48%	Firm
Hydro - All variants	Low	159.562	39.792	1.242.961	679.088	64%	13%	24%	
Biomass - Thermochemical conversion	Low	409.953	127.000	3.388.266	223.606	56%	21%	40%	
Biomass - Biochemical conversion	Low	42.047		288.582		42%	13%		
Geothermal - High enthalpy	Low	814	945	12.628	18.651	50%	14%	35%	
Geothermal - Low enthalpy	Medium	64							Secondary
Ocean - All variants	Low	248	2.513	537	5.299	57%	22%	33%	
Hydrogen & fuel cells - Renewable hydrogen	Low	Negligible	Negligible / Uncertain	Negligible	Negligible / Uncertain	36%	22%	21%	
Hydrogen & fuel cells - Proton-exchange membrane fuel cells	Low								
Hydrogen & fuel cells - Solid oxide fuel cells	Medium								
Storage - Batteries	High	350	2.650	1.400	12.600	28%	11%	20%	Firm
CO2 Capture - All variants	High	Negligible	1.083	Negligible	Uncertain	38%	13%	33%	Secondary
CO2 Storage - All variants	Medium	Not applicable	Not applicable	Not applicable	Not applicable			33%	
CO2 Reuse - Carbonate mineralisation	Low	Not applicable	Not applicable	Not applicable	Not applicable	Not available		26%	
CO2 Reuse - CCU fuels	Medium	Not applicable	Not applicable	Not applicable	Not applicable	Not available			
Flexible conventional - Gas engines	Low	212.280	79.512	1.562.558	699.818	Not available	Not available	32%	
Flexible conventional - Gas turbines	Medium					Not available	Not available		Secondary
Heat pumps	Low	30.000	26.000	84.000	76.000	Not available	24%	29%	

* Level of aggregation driven by expert assessment in summary papers

In task 4, a detailed assessment of the dependencies for wind energy, solar PV and battery energy storage technologies was carried out. This assessment aimed to analyse the criticality and risk of the identified dependencies in depth, and to identify potential additional critical dependencies based on an assessment of the whole value chain (Figures 1-3, 1-4, 1-5). For the assessment, industry stakeholders were consulted and an extensive literature research was performed.

Figure 1-3 Analysed value chain for wind (yellow: critical dependencies found within the value chain)

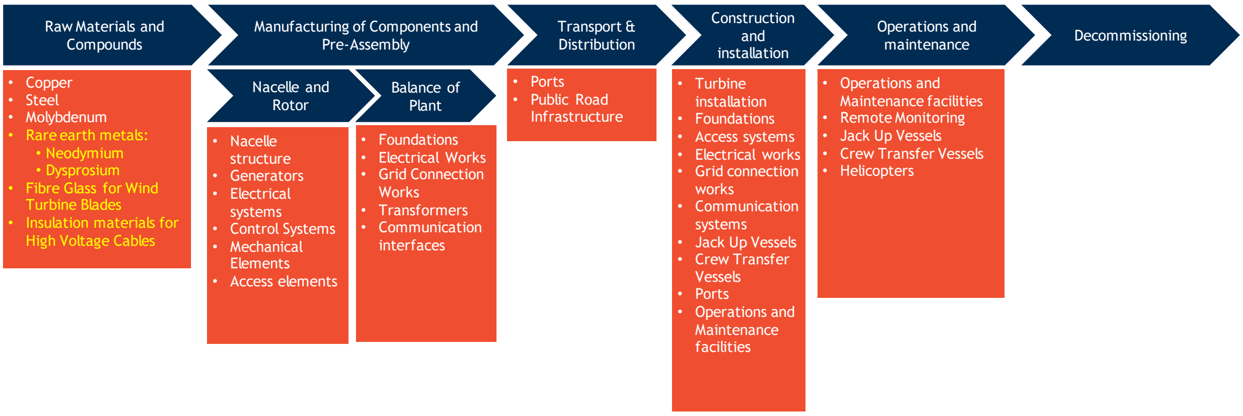


Figure 1-4 Analysed value chain for Solar PV (yellow: critical dependencies found within the value chain)

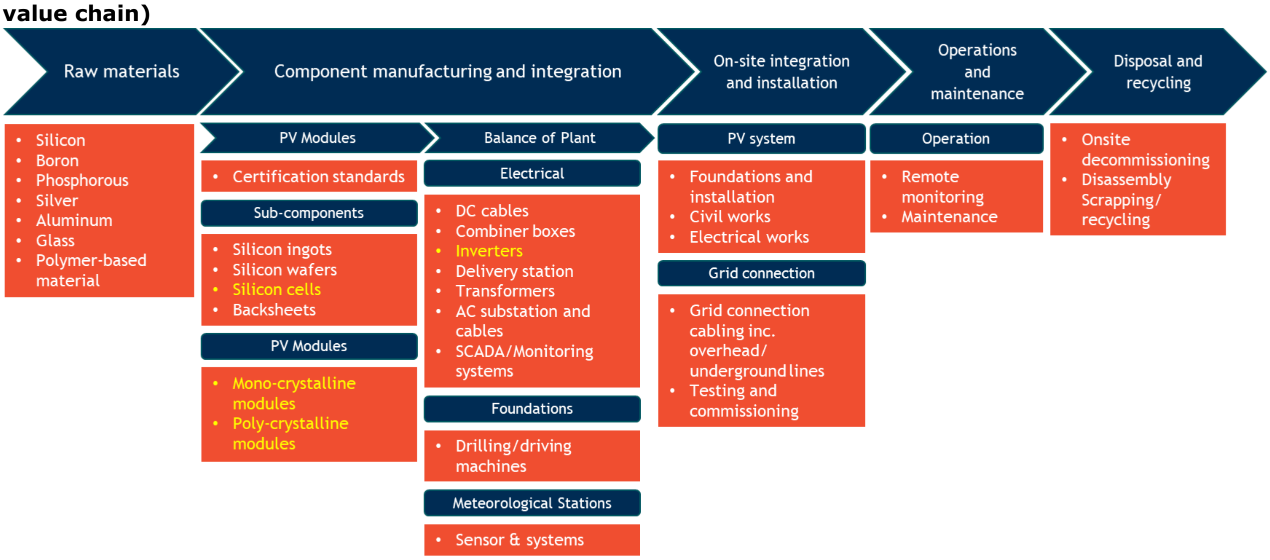
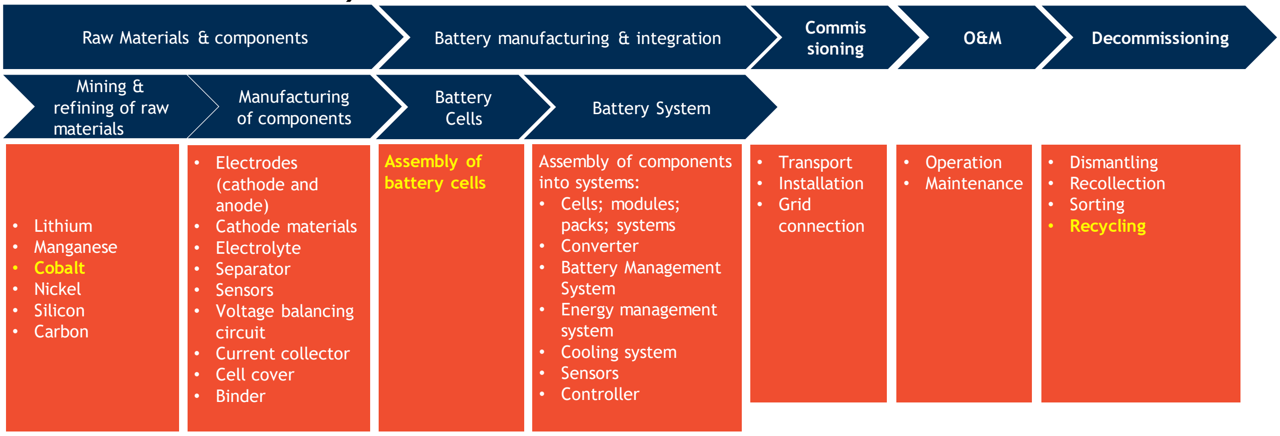


Figure 1-5 Analysed value chain for battery storage technology (yellow: critical dependencies found within the value chain)



The main critical dependencies that were found based on the assessment of the value chains of wind, solar PV and Battery Energy Storage Technology are summarised in Table 1-3. Possible policy measures to address these main critical dependencies for the three technologies are discussed in this report.

Table 1-3 Critical dependencies for low-carbon energy technologies examined in the Task 4 'detailed assessment'

Wind	Solar PV	Battery Energy Storage Technology
1. Neodymium 2. Dysprosium 3. High Voltage Insulation Cables 4. Fibreglass 5. Insulated-gate bipolar transistors (IGBTs)	1. Cells 2. Modules 3. Inverters	1. Cobalt 2. Cells

1.3 Scope and objectives of this report

In order to arrive at clear-cut policy recommendations that fit within current overall policies of the European Commission, this report has the following specific objectives:

- Development of a framework for analysis for identification of possible new energy technology dependence mitigation measures needed, based on theoretical literature as well as on an examination of existing measures in this field;
- Identification and discussion of possible additional policy mitigation measures;
- Provision of policy recommendations on mitigation measures and strategies to DG RTD of the European Commission and other relevant stakeholders in this field.

Referring to the terms of reference, this report combines deliverables D5.1 (mitigation measures) and D6 (policy recommendations).

1.4 Reading guide

In line with the scope and objectives, this report is structured as follows:

1. Overview;

2. Possible mitigation measures for critical technology dependencies;
3. Policy recommendations and actions;
4. References.

Annex A contains an overview of existing energy technology dependence mitigation policies based on which the framework for analysis was developed, Annex B an overview of academic literature on the topic that was studied and Annex C provides the detailed recommendations to mitigate the dependencies for wind, solar PV and battery energy storage technology.

Details about the analyses performed in task 1 to 4 in this project can be found in the separate reports on these tasks.

2 Possible mitigation measures for critical technology dependencies

In the broad-brush analysis carried out in Task 3 of this project, wind energy, solar PV and battery energy storage were found to be the main areas of concern regarding critical energy technology dependencies. In task 4, the value chains of these technologies and in total ten specific critical dependencies within the value chains were examined in more detail (Table 1-3). This chapter will examine what policies are already in place to mitigate against these ten critical dependencies and what additional measures could be considered.

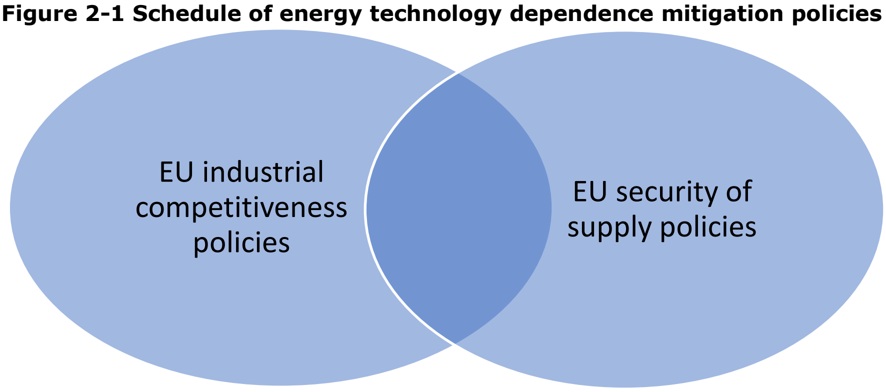
2.1 Framework for analysis

In order to establish a framework for analysis for policy measures needed to address critical dependencies, existing EU energy technology dependence mitigation measures and a selection of important academic sources on the topic were studied. These can be found respectively in Annex A and B of this report.

In line with the definition of critical dependencies used in this project, the associated mitigation policies can be split into two main areas: On one hand there are **security of supply policies** that are directed at reducing the dependency on foreign imports as such, on the other hand there are **EU industrial competiveness policies** that aim to establish an important market position for EU industry in future energy technologies.

One conclusion that can be drawn from the analysis is that EU industrial competiveness policies and EU security of supply policies do overlap, but not completely (Figure 2-1).

Figure 2-1 Schedule of energy technology dependence mitigation policies



EU industrial competitiveness policies basically can consist of

- Demand-side measures (stimulating general demand for European and non-European low-carbon energy technologies in the home market by e.g. pricing measures like subsidies or taxation or direct regulation like standard setting for e.g. near-zero energy buildings);
- Supply-side measures (stimulating EU-based assembly and production by e.g. subsidies, taxation, dedicated support for specific low-carbon technologies) but also by circular economy measures like stimulating improved efficiency of production or recycling);

- RD&I measures (stimulating RD&I for low-carbon energy technologies in various Technology Readiness Level (TRL) stages up to large-scale implementation, coordinating private and public RD&I efforts covering the whole value chain looking for possible substitutes or efficiency measures in case that dependencies exist);
- Trade measures (export stimulation of low-carbon energy technologies e.g. via export guarantees, loans).

Security of supply policies can be split into **preventive policies** on one hand and **crisis management and containment** policies on the other hand. The first category of measures is directed at the prevention of any dependency before it occurs. The second category is meant to contain a dependency crisis once that a sudden supply disruption has occurred. Preventive security of supply measures can consist of

- Demand-side measures (limiting demand for products for which a dependency might occur based on dependency foresight studies.);
- Supply-side measures (stimulating EU-based raw materials extraction as well as EU-based assembly and production by measures such as subsidies, tax reductions, specific derogations, dedicated innovation and commercialization facilities, stimulating improved efficiency of production, recycling);
- RD&I measures (stimulating RD&I for substitutes potentially mitigating technology dependencies);
- Trade measures (import limitations, diversifying countries of origin, creating balanced trade relationships and mutual dependencies).

Security of supply crisis management and containment measures can consist of

- Emergency stocks (in particular stocks of critical raw materials within the EU that can be used in case of sudden supply disruptions);
- Diversifying supply and associated infrastructures (e.g. reverse flow infrastructure in the case of gas, diversifying supply sources to produce electricity);
- Crisis preparation plans and process management.

Looking at overlaps of possible EU industrial competitiveness and security of supply policies, it can be seen that most competitiveness policies are in fact also beneficial to security of supply. Only policies that stimulate demand for low-carbon technologies without also stimulating supply have a potential negative impact on security of supply: if demand within the EU increases without EU supply following suit, this will lead to an increased import from foreign suppliers and hence to larger dependencies.

On the side of security of supply, most preventive policies also have co-benefits in EU technology competitiveness policies. Only raw materials exploration and diversifying import by countries of origin seem to have little benefits for industrial competitiveness, unless the raw materials exploration itself has a high-tech component. Neither do security of supply crisis management policies seem to have many co-benefits for EU technology leadership: maintaining emergency stocks by itself does not involve a technological component, nor does the preparation of emergency plans. Only diversifying supply and building resilient infrastructures (e.g., the reverse-flow infrastructure for natural gas that has been installed throughout the EU in recent years) might be seen to some extent as a basic condition for high-tech low-carbon supply.

These considerations lead to the framework for analysis summarized in Table 2-1. It consists of four categories of possible energy technology dependence mitigation policies, out of which the category of measures that combines benefits in EU industrial competitiveness and security of supply obviously is the preferred one. Nevertheless, the other categories of policies also should be taken into account when considering dependence mitigation measures as defined in this project. The framework will be used in this chapter to analyse in more detail the detailed dependencies identified in Task 4 of this project, before returning to more general dependence mitigation strategies in the areas of wind, solar PV and battery energy storage in the next chapter.

Table 2-1 Main dependency policies in relation to EU industrial competitiveness and security of supply

EU technology leadership only	EU industrial competitiveness and security of supply	Security of supply only – preventive policies	Security of supply only - crisis management
○ Demand support, price measures, subsidies, taxation, standard setting ○ Trade measures, export support	○ EU-based RD&I for substitution ○ EU-based assembly and production ○ EU-based recycling facilities ○ Increased efficiency / produce for re-use ○ Improving EU access to global markets	○ EU-based primary materials production ○ Diversification of countries of origin	○ Emergency stocks ○ Diversity of energy sources, flexible infrastructures ○ Crisis preparation plans

2.2 Wind

With a total net installed capacity of 168.8 GW (153.0 GW onshore and 15.8 GW offshore), wind energy is already a major form of power generation capacity in Europe, and its share is expected to increase substantially in the years to come. Wind turbines have become a mature and highly sophisticated electricity generation technology. Current technology developments are aimed at cost reductions and efficiency improvements to meet the ambitious targets for reduction of the cost of energy. Every part and component of the wind turbine plays a significant role in how efficient a wind turbine operates.

Within the wind energy value chain, five potential wind technology dependencies were examined in the Task 4 analysis: neodymium, dysprosium, high voltage insulation materials, fibreglass and Insulated-gate bipolar transistors (IGBTs). Table 2-2 summarizes the results of the detailed analysis of the dependencies for wind energy.

Table 2-2 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%[2]	Low	Low	No/limited	Not applicable
Dysprosium	>99%	99%[3]	Low	Low	Yes - in progress	Not applicable
HVDC insulation materials	Low	91%	Low	Medium	Yes - in progress	Stable
Fibre glass	>35%	87%	Low	Medium	Yes - available	Declining
IGBT	Low	70%	Low	High	No/limited	Stable

** See Task 4 for exact definition of judgements 'low', 'medium', 'high'*

Main conclusions from the Task 4 detailed dependency analysis for wind energy were:

- Neodymium and dysprosium are the main critical dependencies in the wind sector;
- For fibreglass, present dependencies give some reason for concern, but an urgent need for action at this moment is not foreseen;
- HVDC insulation materials and IGBT are not to be considered as critical dependencies based on the outcomes of this study;
- The industry representatives interviewed for this study did not express particular concern about dependencies in the wind energy supply chain.

Regarding dependence mitigation measures for wind energy already in place, several policies relating to industrial competitiveness **in wind energy** can be distinguished. The Revised Renewable Energy Directive, with its target of 32% renewables by 2030 and the National Renewable Energy Action Plans, serve as a general framework to stimulate the home market for all renewable energy technologies[4]. The Strategic Energy Technology Plan (SET-Plan) identifies nine key innovation actions that focus on wind off-shore, including system integration, development of floating offshore turbines, industrialisation, turbine development and basic materials science[5]. While decommissioning is included under 'industrialisation' no specific options for this topic are envisaged. Yet, increasing the average lifetime of wind turbines from currently around twenty to thirty years[6] could substantially increase not only efficiency and accelerate cost reductions, but also contribute to reducing energy technology dependency risks. The topic of 'materials science' includes research into new materials for blades, structures, mechanical and electrical components. The European Technology and Innovation Platform (ETIP) for wind energy further provides a vital network for future developments in the wind energy sector consisting of research and industry representatives[6].

[2] CR4 country
[3] CR4 country
[4] See http://europa.eu/rapid/press-release_STATEMENT-18-4155_en.htm
[5] SET Plan Steering Committee, Offshore wind implementation plan, 13 June 2018
[6] As suggested by one workshop participant to the ETD project (10 October 2018)
[6] See https://etipwind.eu/

Concerning **security of supply** measures that are also relevant for wind energy, the EU Raw Materials Initiative[7] is one example, although it is limited in terms of its coverage of raw materials relevant to wind.

2.2.1 Dependencies 1 & 2: neodymium & dysprosium

The rare earth elements **neodymium** and **dysprosium** emerged as the main critical dependencies for the future EU wind energy sector in Task 4. Both raw materials are used in wind turbines as part of an alloy in permanent magnets for direct drive generators (i.e. generators without a gearbox). This type of low-speed generators is increasingly used for offshore wind turbines since it can reduce the size of turbines and therefore costs. Therefore, demand for the two rare earth elements is expected to increase substantially in the future, with previous demand estimations already outdated. Whereas JRC in 2013 still estimated an annual demand of about 1,200 tonnes for neodymium in 2030 (Table 2-3), current demand for neodymium already amounts to 2,600 to 2,900 tonnes (dysprosium 260 to 290 tonnes) and more recent estimates assume that this demand might reach up to 8 000 tonnes/year in 2030[8]. This represents about 30% of the current annual global production or about 10% of the projected production of neodymium in 2030.

Table 2-3 Estimations for the annual EU demand of critical rare earth materials for wind energy (European Commission Joint Research Centre Institute for Energy and Transport, 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).

Despite the fact that neodymium and dysprosium can be found in many places in the world (including Sweden, Denmark, Finland, Greece and Spain), up to 90% of neodymium supply to the EU is currently imported from China. For dysprosium this amounts to 99%.

- **Existing energy technology dependence mitigation measures**

The home market for wind energy (although not for neodymium and dysprosium itself) is stimulated at the EU level by target setting and by a large variety of financial support measures (feed-in tariffs, subsidies, tax deductions) and other stimulating measures (e.g. preferential access to the grid for renewables in some countries) that are outlined in the National Renewable Action Plans. EU raw materials policy is also already receiving substantial attention at the EU level, most comprehensively through the Raw Materials Initiative (RMI) with its three pillars supply from global markets, supply from European sources and resource efficiency and other initiatives such as the 2015-18 EU STRADE initiative[9]. Neodymium and dysprosium as rare earth minerals also feature on the 2017 revised list of Critical Raw

[7] See https://ec.europa.eu/growth/sectors/raw-materials/policy-strategy_en and Annex A
[8] WindEurope (2017) Wind in Power - 2016 European statistics. Brussel: Wind Europe
[9] http://stradeproject.eu/index.php?id=3

Materials (CRMs)[10] and therefore are already to some extent a focus point of existing policies.
Opening of new mining sites in the EU is expensive and requires long preparations. Market entry of new mines and diversification from the current almost monopoly supplier China is therefore difficult. Initial examination of potential mining sites in Sweden and Estonia – alongside other potential sites in California and Australia – has been discontinued because of environmental considerations and dropping world market prices[11].

Similarly, substitution of dysprosium and particular neodymium at competitive price levels at this moment is not yet possible. Several research and innovation (R&I) projects funded by the European Commission on the topic of substitution of these elements have taken place in recent years under the 7th Framework Research Programme (e.g. ROMEO – developing magnets free of rare earth elements[12]), but while for dysprosium some substitution options are under development, this does not hold yet for neodymium.

Recycling facilities of the raw materials neodymium and dysprosium have not yet taken off due to the fact that wind energy is a relatively new technology, with hardly any wind turbines that are in a replacement stage yet. Finally, stockpiling of rare earth elements as a measure of last resort so far was only considered in the UK's proposed Minerals Strategy. Table 2-4 assesses existing EU dependence mitigation policies for neodymium and dysprosium along these lines.

Table 2-4 Assessment of EU energy technology dependence mitigation policies for neodymium and dysprosium

EU industrial competitiveness only	EU industrial competitiveness and security of supply	Security of supply only – preventive policies	Security of supply only - crisis management
○ Demand support, price measures, subsidies, taxation, standard setting ○ Trade measures, export support	○ EU-based RD&I for substitution ○ EU-based assembly and production ○ EU-based recycling facilities ○ Increased efficiency / produce for re-use ○ Improving EU access to global markets	○ EU-based primary materials production ○ Diversification of countries of origin	○ Emergency stocks ○ Diversity of energy sources, flexible infrastructures ○ Crisis preparation plans

Green: already sufficient policy action/ no further action recommended Yellow: additional policy action possible; Red: additional policy action recommended; Black: not applicable/not recommended

[10] http://criticalrawmaterials.org/european-commission-publishes-new-critical-raw-materials-list-27-crms-confirmed/
[11] Rabe, W. K. (2017). China's supply of critical raw materials: Risks for Europe's solar and wind industries? Energy Policy, 692-699.
[12] https://cordis.europa.eu/result/rcn/184080_en.html

- **Possible additional measures**

The investigation of already existing policies shows that many policy measures that address dependencies for neodymium and dysprosium are already taken. On top of that, additional measures so far show difficult and have had limited success. Nevertheless, the analysis made in this report also shows that the extent of import shares, market concentration, ease of market entry and the availability of substitutes - in particular for neodymium – still give reason for concern. Therefore at least a reinforcement of existing measures would be required to address the currently insufficient scores for dependency indicators. Some options for such reinforcement that add specifically to the SET plan's actions for wind offshore and to the RMI seem available.

Regarding measures that could contribute to mitigation of energy technology dependence and to EU industrial competitiveness, in the first place the search for affordable substitutes for both rare earth minerals could be expanded. This is most urgent for neodymium, where so far, no likely candidates for such substitutes have been found. Substitution research for neodymium and dysprosium is also taking place outside the EU, for instance in Japan and the United States[13]. Joining forces with these partners could be beneficial. Further, since the SET-plan's wind offshore actions agreed in 2018 already foresee a reinforcement of materials science research required for further wind offshore development[14], here such research could be placed. In addition, the more general Horizon2020 and the future Horizon Europe programme could be used.

Secondly, possibilities for efficient resource use and recycling of rare earth elements should be fully exploited. The quantities of neodymium and dysprosium needed per turbine are small, which poses new technological challenges to such small-scale recycling. Despite challenging separation techniques required, recycling techniques for neodymium and dysprosium are already available and some wind turbine producers have already begun planning a circular approach to these raw materials. Again, the SET-plan's wind offshore actions seem the right place for this, as under the announced action of 'industrialisation' also – but without further specification – the topic of decommissioning is included.

Thirdly, the RMI could be further strengthened to address the critical dependencies for neodymium and dysprosium. As part of the RMI, several platforms for dialogue are in place such as the industry-level international commodity study groups, e.g. zinc, lead, nickel and copper[15]. The aim of EU participation in these study groups is to discuss market trends, exploration, extraction, production, and trade developments. Although this framework is in place, there is no such study group yet specifically focusing on neodymium or dysprosium.

Preventive measures that do not have co-benefits to EU industrial competitiveness policies are less attractive than those that do have such benefits. Nevertheless, in the case of the critical dependencies of neodymium and dysprosium these could also be part of a package of additional mitigation measures to be considered, in particular since China is acting as a near monopoly supplier for these raw materials.

[13] See e.g. https://newsroom.toyota.co.jp/en/corporate/21139684.html (Toyota) and http://web.mit.edu/12.000/www/m2016/finalwebsite/solutions/alttechnology.html (MIT)
[14] SET Plan Steering Committee, Offshore wind implementation plan, 13 June 2018
[15] See https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/international-aspects_en

In this respect, possibilities for mining in the EU could be further examined in order to overcome the initial difficulties for such exploration. Important points in this examination should be the strict environmental legislation in the EU and frequent local protests against new technologies that have an impact on the landscape as well as sustainable mining and public support - locally and nationally. Also, in light of fluctuating raw materials costs on the world market, the possibilities for mining on demand in such a way that this does not entail expensive start-up costs could be investigated. The expansion of resource expertise and reserves mapping in the EU represent further basic conditions for domestic mining activities in the EU. These actions are already addressed by the implementation plan for the second RMI pillar, such as the exchange of best practices, reports on national mining policies and the development of a knowledge base[16], but could be examined more specifically for neodymium and dysprosium.

Intensifying multilateral and bilateral trade policy efforts to reduce the Chinese market power for these raw materials would be another preventive option to be examined. Since 2013, negotiations for an EU-China Investment Agreement are ongoing and in July 2018 the 18th round of these negotiations has been held[17]. Furthermore, the ongoing EU – China Energy Dialogue has developed a Roadmap on Energy Cooperation[18]. In future implementation plans of this Roadmap, the issue of neodymium and dysprosium dependency could be specifically addressed. Stimulating trade relationships with other potential suppliers, for example with Australia, could also go along this line.[19].

Stockpiling of neodymium and dysprosium could finally be considered as an additional **crisis management and containment measure of last resort**. However, contrary to fossil supply where past crises have shown that a supply disruption of only a few days could result in major energy shortages in the EU without stockpiling, a temporary supply disruption of raw materials for wind turbine production could lead to energy supply shortages only in the longer-term. While such stockpiling is a potential additional mitigation policy, it does not seem a very urgent or desirable measure therefore – even more because stockpiling is a relatively expensive option.

Possible additional mitigation measures to reduce dysprosium and neodymium dependencies

Technology leadership and preventive policies

Expand EU RD&I for neodymium and dysprosium substitutes, most urgently for neodymium and possibly in cooperation with Japan and the US as partners. This could be done in particular under the SET implementation plan wind offshore action 'materials science', next to general research stimulation options under Horizon2020 and Horizon Europe;

Examine economically viable opportunities for small-quantity recycling, as in the case of neodymium and dysprosium. This could be done in particular under the SET implementation plan wind offshore action 'industrialisation';

Install separate expert groups on neodymium and dysprosium under the Raw Materials Initiative;

[16] See https://ec.europa.eu/growth/sectors/raw-materials/policy-strategy/sustainable-supply-eu_en

[17] EC (2018) Report of the 18th round of negotiations for the EU-China Investment Agreement, Brussels

[18] EC and PRC (2016) EU-China Roadmap on energy cooperation 2016-2020

[19] In May 2018, the Council of the European Union authorised opening negotiations for a trade agreement between the EU and Australia. See http://ec.europa.eu/trade/policy/in-focus/eu-australia-trade-agreement/

General extension of lifetimes of wind turbines by dedicated RD&I in order to increase materials efficiency and reduce dependency risks.

Preventive policies only

Further examine mining options for neodymium and dysprosium within the EU under the second pillar of the Raw Materials Initiative, in particular investigating environmentally and economically viable possibilities for mining on demand at peak times only;

- Intensify multilateral and bilateral trade policy efforts to reduce the market power of China as a near monopoly supplier. Include neodymium and dysprosium dependency as an issue in future implementation plans of the EU-China energy dialogue;
- Intensify trade relations with neodymium/dysprosium suppliers other than China, in particular with Australia. This could be done under the recently started negotiations for an EU-Australia trade agreement;

Crisis management and containment

- Consider stockpiling of neodymium and dysprosium as an ultimate option to reduce current dependencies.

2.2.2 Dependency 3: Insulation materials for high voltage cables

Recent offshore renewable energy generation systems require specific cable designs with specific capabilities as the industry has been experiencing a significant technological development. Without doubt, high voltage cables play a critical role since longer distances to shores, deeper waters and higher unit power are required for today's offshore wind projects. Therefore, the importance of high voltage offshore cables is getting bigger. The latest available technology in offshore renewable energy generation requires specific cable designs with specific capabilities. Cross-Linked Polyethylene (XLPE) is a key material in these cables, of which the supply might become an important issue in the future. The low number of active players in this complex niche market and the high degree of international ownership (despite significant EU-based production) might present some limited dependency risks in the future, but overall the market for high-voltage cables was assessed to be a non-critical dependency in particular due to low import shares and stable competitiveness trends (See Table 2-5).

- **Existing energy technology dependence mitigation measures**

There are some limited policy measures that could be considered mitigation measures for high-voltage cable dependencies already in place. These concern RD&I for substitution mainly. Potential **substitutes** for XLPE include Ethylene Propylene Rubber (EPR) and P-laser technology (from the cable manufacturer Prysmian). Although EPR does not have fully equivalent properties to XLPE, it is already being used in commercial projects - indicating sufficiently high technology readiness levels for substitution.

Table 2-5 Assessment of EU energy technology dependence mitigation policies for high-voltage cables

EU industrial competitiveness only	EU industrial competitiveness and security of supply	Security of supply only – preventive policies	Security of supply only - crisis management
○ Demand support, price measures, subsidies, taxation, standard setting ○ Trade measures, export support	○ EU-based RD&I for substitution ○ EU-based assembly and production ○ EU-based recycling facilities ○ Increased efficiency / produce for re-use ○ Improving EU access to global markets	○ EU-based primary materials production ○ Diversification of countries of origin	○ Emergency stocks ○ Diversity of energy sources, flexible infrastructures ○ Crisis preparation plans

Green: already sufficient policy action/ no further action recommended Yellow: additional policy action possible; Red: additional policy action recommended; Black: not applicable/not recommended

- **Possible additional measures**

Market concentration in high-voltage insulation materials and barriers to market entry were considered 'medium' risks for insulation materials. These risks could be particularly mitigated by stimulating substitution within the EU, with a focus on EPR and P-laser applications. A shift towards HVDC for longer cables in the case of increasingly remote offshore wind farms could contribute to such development, as the material properties of EPR are more suitable for these applications. P-laser technology further has a higher range of operating and emergency temperatures compared to XLPE, with potentially lower production costs, also illustrating that the feasibility of this possible substitute should be further examined. Next to a more general stimulation under Horizon2020 and Horizon Europe, these issues could be specifically addressed under the 2018 SET wind offshore implementation plan, actions 'system integration' and 'materials science'[20].

Other actions in the field of **preventive-only** policies and even less so **crisis management and containment** policies do not seem to be appropriate at this moment, given the limited dependency risks for the EU in the field of high-voltage cables at this moment.

Possible additional mitigation measures to reduce high-voltage insulation dependencies

Technology leadership and preventive policies

- ○ Stimulate the continued development of possible substitutes for XLPE such as EPR and P-laser. This could take place under Horizon2020 and Horizon Europe programmes, as well as more specifically under the Wind Offshore SET implementation plan, actions 'system integration' and

[20] SET Plan Steering Committee, Offshore wind implementation plan, 13 June 2018

'materials science'.

Prevention–only policies

- None recommended

Crisis management and containment

- None recommended

2.2.3 Dependency 4: Fibreglass for wind turbine blades

Fibreglass for wind turbine blades is assessed to represent a moderate dependency risk for wind energy. It is an essential material used in the production of wind turbine components such as turbine blades, which are 60% fibreglass. Approximately 75% of the wind turbine blades in the EU and the rest of world are manufactured from fibreglass composites while the rest are manufactured with carbon fibre. The Asia-Pacific region dominates the global fibre glass market. China is the biggest manufacturer of fibre glass in the world, with high quality fibre glass produced at relatively low costs.

As fibreglass production is an essential component for wind turbines in the future this might lead to an increasing dependency risk, since a proportion (35% as a share of total EU consumption) is currently being imported. It is a matter of concern that the competitive position of EU industry for this material seems to be worsening, even more so as in the past there have been criticisms of the unfair dumping of fibreglass by China in the EU[21] that have led to the installation of anti-dumping measures by the EU[22].

- **Existing energy technology dependence mitigation measures**

Anti-dumping measures, RD&I and production of alternatives to fibreglass are already in place as measures reducing the dependency risks in the fibreglass market (Table 2-6). Carbon fibre is currently considered a promising alternative to fibreglass. This fibre shows higher stiffness and lower density than the fibreglass, allowing for thinner, stiffer and lighter blades. However, carbon fibre has relatively lower damage tolerance, compressive strength and ultimate strain, and is much more expensive than fibreglass. Other possible alternatives to fibreglass are aramid and basalt fibres, hybrid composites of glass and carbon, and in some cases natural fibres from sisal, flax, hemp, and jute[23]. In the carbon composites market, the EU already has an important position, with other main producers in Japan and the United States[24].

[21] http://www.glassfibreeurope.eu/wp-content/uploads/GFEBriefingDocument.pdf
[22] COMMISSION IMPLEMENTING REGULATION (EU) 2017/724 of 24 April 2017
[23] Mishnaevsky, Leon, Kim Branner, Helga Nørgaard Petersen, Justine Beauson, Malcolm McGugan and Bent F. Sørensen (2017) Materials for Wind Turbine Blades: An Overview, Materials 2017, 10, 1285
[24] Pavel, C.C. and Blagoeva, D.T. (2017) Materials impact on the EU's competitiveness of the renewable energy, storage and e-mobility sectors, JRC science for policy report

Table 2-6 Assessment of EU energy technology dependence mitigation policies for fibreglass

EU industrial competitiveness only	EU industrial competitiveness and security of supply	Security of supply only – preventive policies	Security of supply only - crisis management
○ Demand support, price measures, subsidies, taxation, standard setting ○ Trade measures, export support	○ EU-based RD&I for substitution ○ EU-based assembly and production ○ EU-based recycling facilities ○ Increased efficiency / produce for re-use ○ Improving EU access to global markets	○ EU-based primary materials production ○ Diversification of countries of origin	○ Emergency stocks ○ Diversity of energy sources, flexible infrastructures ○ Crisis preparation plans

Green: already sufficient policy action/ no further action recommended Yellow: additional policy action possible; Red: additional policy action recommended; Black: not applicable/not recommended.

- **Possible additional measures**

Market concentration and a declining market share in the fibreglass market are the main factors of concern for fibreglass, according to the Task 4 analysis. Regarding **prevention only policies**, currently EU anti-dumping measures already assure some degree of protection to EU producers. Further protective trade measures to assure access to global markets of EU producers therefore do not seem to be a very promising way forward in the competition with Chinese suppliers. The current oversupply of fibreglass in China will also hinder a diversification to other countries that could be alternative suppliers, although here several options would be possible (e.g. Norway, Malaysia, Egypt).

More promising therefore seems to be **EU industrial competitiveness and preventive policies** that invest in a reinforcement of current support for the development of alternatives to fibreglass, in particular carbon. This holds even more, as the EU already has a relevant market position in this field, with suppliers in Belgium and Germany. Again, here the SET plan and Horizon2020 / Horizon Europe seem the most appropriate mechanisms to direct such a reinforcement of RD&I efforts. **Crisis management and containment measures** do not seem appropriate for fibreglass, given the medium dependency risk only.

Possible additional mitigation measures to reduce fibreglass dependencies

Technology leadership and preventive policies

- Increase stimulation of development of RD&I that can provide an alternative to fibreglass, in particular carbon, through a reinforcement of activities foreseen in SET plan and through general RD&I stimulation under Horizon2020 and Horizon Europe.

Prevention–only policies

- None recommended

Crisis management and containment

- None recommended

2.2.4 Dependency 5: Insulated Gate Bipolar Transistors (IGBTs)

Correct functioning of all electronic components is necessary for the operation of a wind turbine. Insulated-gate bipolar transistors (IGBTs) are an important component in these electronics for which there is currently no alternative, as they connect with wind inverters for the necessary variable speed operation of the turbine. IGBTs are assessed in the Task 4 analysis not to represent a critical dependency for wind energy as their import share is low and the easy of entry to the IGBT market seems high. Nevertheless, market concentration in the sector may require some further attention. the current market leader in IGBT prosecution is Infineon in Austria, with a 26% market share[25], but interviewees[26] highlighted the role of Switzerland[27] and the UK[28] in the production of IGBT technology and Japan as other important IGBT producers.

- **Existing energy technology dependence mitigation measures**

Demand for IGBTs is expected to increase substantially in the coming years, not only because of growth of the wind energy market but also of the market for electrical vehicles. Still, in correspondence with the low risk assessed for IGBTs, there do not seem to be any specific EU policy measures addressing IGBT import dependencies.

[25] https://www.marketresearchfuture.com/reports/igbt-market-2854
[26] Interview with TenneT representative.
[27] ABB Semiconductors
[28] IXYS UK Westcode Ltd.

Table 2-7 Assessment of EU energy technology dependence mitigation policies for IGBTs

EU industrial competitiveness only	EU industrial competitiveness and security of supply	Security of supply only – preventive policies	Security of supply only - crisis management
○ Demand support, price measures, subsidies, taxation, standard setting ○ Trade measures, export support	○ EU-based RD&I for substitution ○ EU-based assembly and production ○ EU-based recycling facilities ○ Increased efficiency / produce for re-use ○ Improving EU access to global markets	○ EU-based primary materials production ○ Diversification of countries of origin	○ Emergency stocks ○ Diversity of energy sources, flexible infrastructures ○ Crisis preparation plans

Green: already sufficient policy action/ no further action recommended Yellow: additional policy action possible; Red: additional policy action recommended; Black: not applicable/not recommended

- **Possible additional measures**

At this moment, given the results of the Task 4 analysis, no specific additional measures for the IGBT market seem recommendable. For the longer run however, the current lack of substitutes for IGBT technology might give rise to the search for alternatives to this technology in the future.

Possible additional mitigation measures to reduce IGBT dependencies

Technology leadership and preventive policies

- None recommended, although the development of alternatives to IGBTs could be a direction for RD&I in the future

Prevention only

- None recommended

Crisis management and containment

- None recommended

2.3 Solar PV

Solar PV is, like wind, a major growth area for future low-carbon energy in Europe. Thin-film and crystalline silicon technologies are the two common options currently available, with the latter by far mostly used with a share of 95% of global production (poly and mono combined).[29] Therefore only crystalline silicon technology was analysed in Task 4 of which three main dependencies were examined in the detailed analysis: cells, modules and

[29] Fraunhofer Institut (2018) Photovoltaics Report. https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

inverters. The quantitative findings of this analysis are summarized in Table 2-8. Main conclusions of the analysis were:

- Solar cells are confirmed as a critical dependency;
- Solar modules are also a critical dependency, albeit slightly less critical than solar cells;
- For solar inverters there is a strong EU industry and no dependency on external suppliers;
- The dependency on solar cells and modules is a risk for EU industrial leadership in renewables but not for security of supply;
- There is no current dependency for inverter manufacturing, but capacities tend to shift to areas outside the EU.

Table 2-8 Summary 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

** See Task 4 for exact definition of judgements 'low', 'medium', 'high'*

2.3.1 Dependencies 1 and 2: PV Cells and modules

Cells and modules are often manufactured by the same company. Once the cells are produced, assembling them into modules is a fairly straight-forward process. In regional markets, therefore module production capacity is reflected in cell production capacity, and vice-versa. As a result, dependencies of cell and module manufacturing capacity are highly related and for that reason here are analysed together.

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 include seven firms from China, one from Korea (Hanwha Q-Cells), one from Canada (Canadian Solar), and one from the USA (First Solar). Out of the top-4 companies, controlling 33% of the market, three are Chinese[30]. Only 2% of solar cells are currently produced in the EU, particularly in Germany. A slightly higher proportion of solar modules than cells is produced in Europe, although module production too remains dominated by Asia[31].

- **Existing energy technology dependence mitigation measures**

Existing policy approaches relating to EUindustrial competitiveness in the field of solar PV include a demand push through renewable energy target setting, standard setting through

[30] Global data (2017) Global solar photovoltaic module shipments ranking.
[31] https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

e.g. the promotion of Nearly Zero Energy Buildings via the Energy Performance of Buildings directive[32] and RD&I stimulation via Horizon2020 and the SET-Plan[33].
The Solar PV Implementation Plan of the SET plan[34] identifies five key technology actions: (1) Major advances to be achieved in PV module efficiency (20% by 2020 and 35% by 2030 compared to 2015 levels); (2) Reduction of turn-key system costs with the introduction of novel, potentially very-high-efficiency PV technologies manufactured at large scale; (3) Improving environmental performance by further enhancement of lifetime, quality and sustainability of PV cells; (4) Enabling mass realization of "(near) Zero Energy Buildings" (NZEB) by Building-Integrated PV (BIPV) through collaborative innovation efforts between the PV sector and the building industry, and; (5) Major advances in manufacturing and installation, for instance by developing PV module and system design concepts that enable fast and highly automated installation. Industry and research networks around solar PV are in particular the Solar Europe Industry Initiative (SEII) and the European Technology & Innovation Platform ETIP-PV[35].

The anti-dumping measures against Chinese solar PV suppliers that were in force between 2013 and 2017[36] can be seen as the main energy-technology dependence mitigation measures for PV in place that relate to **security of supply[37]**. These anti-dumping measures ended in August 2018 with the motivation that "the market situation has not changed to the extent that this would justify a further extension of the measures" [38].

Table 2-9 Existing EU energy technology dependence mitigation policies for PV cells and modules

EU industrial competitiveness only	EU industrial competitiveness and security of supply	Security of supply only – preventive policies	Security of supply only - crisis management
○ Demand support, price measures, subsidies, taxation, standard setting ○ Trade measures, export support	○ EU-based RD&I for substitution ○ EU-based assembly and production ○ EU-based recycling facilities ○ Increased efficiency / produce for re-use ○ Improving EU access to global markets	○ EU-based primary materials production ○ Diversification of countries of origin	○ Emergency stocks ○ Diversity of energy sources, flexible infrastructures ○ Crisis preparation plans

Green: already sufficient policy action/ no further action recommended Yellow: additional policy action possible; Red: additional policy action recommended; Black: not applicable/not recommended

[32] EC 2018/844/EU
[33] See https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan
[34] TWG (2017) Draft Solar PV implementation plan, October 2017
[35] http://climateinitiativesplatform.org/index.php/Solar_Europe_Industry_Initiative_(SEII) and http://www.etip-pv.eu/
[36] EC (2018) Commission decides not to extend trade defence measures on solar panels from China, http://trade.ec.europa.eu/doclib/press/index.cfm?id=1904
[37] However, EU-based PV cell and module production did not significantly increase over this period, which can cast doubts on the effectiveness of this measure in relation to EU industrial competitiveness policies.
[38] See http://trade.ec.europa.eu/doclib/press/index.cfm?id=1904

- **Possible additional measures**

According to the task 4 analysis, import share, market concentration and ease of market entry are the main dependency factors that have to be addressed by additional mitigation policies. Market entry for EU cell and module producers might remain difficult due to lower production costs elsewhere and a possible oversupply in markets due to a reduced growth of the Chinese domestic market, which might lead to more Chinese exports[39].
However, reducing the EU external market concentration and import shares could possibly be attained by rebuilding strategic parts of the EU PV industry. A detailed study on the EU PV industry published in 2017[40] suggests that concerning **EU-based assembly and production**, there could be in particular potential to expand the market for tailored PV products, in which the customers' behaviours are influenced by more than the price of the product and the electricity price alone. This is because of the relatively good market prospects compared to competing world regions, the importance of customer proximity and the relative immaturity of the industry worldwide, which does not yet lead to significant supply chain and scale disadvantages. According to the study over time a strong position in this market segment could not only reduce import dependency but also lead to significant export opportunities across the world.

EU based RD&I for alternative products and substitution technologies could be a second pillar of an EU energy technology dependence mitigation strategy that focuses on strengthening the EU PV industry. Advanced CSi cells, such as HIT and CSi + perovskite, so far show to be promising options for the future that could be developed further in a European context. In addition, integrated applications for the built environment are a market with EU employment perspectives not only in RD&I but also in the electronics and construction sector. Additional advantage of integrated approaches for the built environment are that these are relatively sheltered from international competition due to their location-based nature[41].

A focus on **increasing efficiency** in the production process of solar cells and modules could also be part of this RD&I strategy, particularly with regard to the silver and polysilicon used, while continuing to work on the solar cell efficiency *per se* ultimately results in less solar cell or module demand for the same unit of power rated. This also aligns with wider EU resource efficiency priorities, for example under the Circular Economy Strategy. Innovative technologies for achieving high materials efficiency for solar cells further include 'metal wrap through technology' or 'buried contact'[42].

With the exception of initiatives like the PV-Cycle programme[43], r**euse and recycling** with regard to solar cells and modules are not yet very much developed, since this mitigation option is dependent on end-of-life products, which are not yet available on a larger scale (the average lifespan of a solar cell is expected to be around 30 years[44]). Furthermore, since solar cells and modules are designed involving small sub-components, recycling remains a complex process. It could be helpful to set a strong policy framework and robust RD&I

[39] Energy Trend (2018) Chinese PV industry under pressure, https://www.energytrend.com/news/20180806-12413.html
[40] Trinomics (2017) Assessment of Photo-Voltaics, Rotterdam
[41] Trinomics (2017) Assessment of Photo-Voltaics, Rotterdam
[42] Saga, T. (2015). Advances in crystalline silicon solar cell technology for industrial mass production. https://www.nature.com/articles/am201082.pdf
[43] http://www.pvcycle.org/homepage/
[44] See http://iea-pvps.org/fileadmin/dam/public/report/technical/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf

priorities for improved solar cell design and production in order to target the facilitation of recycling or reuse at later stages. Currently, EU-JRC is examining the possibilities for PV eco-design, with outcomes of the study expected for 2019[45].

Possible additional mitigation measures to reduce solar cell and module dependencies

Technology leadership and preventive policies

- Focus on tailored PV products in which design and aesthetics plays an important role next to price considerations in support for the EU PV cells and modules industry;
- Stimulate European RD&I on improved materials efficiency in solar cell and module technology, including perovskite and HIT options, in lower TRL levels and on building-integrated PV in the higher TRL levels;
- Build coalitions between EU PV, buildings and electronics industry around building-integrated PV;
- Foster PV recycling and design-for-recycle based on ongoing JRC research and through support for industry initiatives like PV-CYCLE and continuously stricter standard setting via the EU Eco-design and Energy Labelling Directives;

Prevention–only policies

- As existing EU import measures against Chinese panels have been recently lifted, new measures of this kind are not likely to be supportive for reducing EU PV dependencies in the near future. However, a close monitoring of solar cell and module market concentration remains necessary, given the high dominance of Chinese producers in this market.

2.3.2 Dependency 3: Inverters

Solar inverters are essential components for the production of electricity from solar PV technology that exist as 'stand-alone', 'grid-connected', 'string', 'micro' or 'central' applications, each with slightly different technical characteristics. The main focus of this report is on string and central inverters. Currently, the EU position in the inverter industry is still relatively good and there is no critical dependency found for inverters according to the outcomes of the task 4 analysis. However, the position of the inverter industry in the EU is under threat because of the lack of local clustering (i.e. the presence of EU wafer, cell and module manufacturers next to the inverter industry) and the efforts of competing regions to gain market share. The risk of a future criticality was also identified in expert interviews carried out in the task 4 analysis[46]. The interviewed experts have expressed concerns around the high market share of a handful of players in this market and that production will further shift to China. Inverter production is now already dominated by Chinese companies. Only two of the top five inverter companies that make up 57% of market share (Huawei, Sungrow, SMA Solar, ABB, and TMEIC) are now located in Europe (SMA Solar in Germany and ABB in Switzerland).

- **Existing energy technology dependence mitigation measures**

[45] http://susproc.jrc.ec.europa.eu/solar_photovoltaics/index.html
[46] See the task 4 report of this study, 'Detailed analysis of selected dependencies'

Whereas inverter dependencies are generally influenced by the development of the overall PV market, currently no specific mitigation measures exist that specifically address the inverter market.

Table 2-10 Existing EU energy technology dependence mitigation policies for inverters

EU industrial competitiveness only	EU industrial competitiveness and security of supply	Security of supply only – preventive policies	Security of supply only - crisis management
○ Demand support, price measures, subsidies, taxation ○ Standard setting ○ Trade measures, export support	○ EU-based RD&I for substitution ○ EU-based assembly and production ○ EU-based recycling facilities ○ Increased efficiency / produce for re-use ○ Improving EU access to global markets	○ EU-based primary materials production ○ Diversification of countries of origin	○ Emergency stocks ○ Diversity of energy sources, flexible infrastructures ○ Crisis preparation plans

Green: already sufficient policy action/ no further action recommended Yellow: additional policy action possible; Red: additional policy action recommended; Black: not applicable/not recommended

- **Possible additional measures**

Inverters now are generally not visible nor recognizable on the PV consumers market. Consumers' purchasing decisions are therefore often made on the basis of the information that is available (price per capacity (EUR/W)) and disregard lifetime performance (EUR/kWh). This is detrimental to manufacturers of products that differentiate on lifetime performance, such as inverters, as well as possibly in the end for consumers themselves, who cannot include all information in their purchasing decisions. Standard setting for panels and inverters under the Energy Labelling Directive therefore could be an informative measure that allows consumers to compare and contrast different products in the market to help them make an informed decision. This should drive demand towards better quality products, hereby also creating a launching market for manufacturers of next generation technologies.

Interviewees noted that the inverter market is increasingly concentrated around large companies, which presents a market-driven dependency. Secondly, critics state that a shift in inverter production to China is expected. Finally, barriers for new capacity relate to high start-up costs, economies of scale and learning curve advantages. Therefore, there is a need to provide incentives to ensure the continuation of (and further develop) **EU-based assembly and production**, whether through EU-level or national-level financial incentives to existing or aspiring companies.

The lack of competition in the sector and the fact that inverters cannot be substituted increase the risk of dependencies emerging in this sector. In order to ensure a diversity of suppliers in the longer term, it may be necessary to implement **preventive policies** to monitor that diversification takes place with the interests of the EU firmly within grasp particularly with respect to market concentrations. Furthermore, it will be important to strengthen the implementation of EU Competition Law to prevent the emergence of uncompetitive practices.

Further, the consideration of the different types of inverters may be possible in the context of EU-wide grid infrastructure, since efficiencies are similar but market shares are different (lower)[47]. The use of a diverse set of inverters would allow flexibility, particularly in cases where single suppliers are dominant. This could be an area of RD&I in which to develop competitive advantage.

Possible additional mitigation measures to reduce solar inverter dependencies

Technology leadership and preventive policies

- Stimulate demand for differentiated products, including high-quality EU inverters, through standard setting in the EU labelling directive;

Prevention only

- No measures recommended.

2.4 Battery Energy Storage Technology

Every year, approximately 800.000 tons of automotive batteries, 190.000 tons of industrial batteries, and 160.000 tons of consumer batteries are imported to the European Union[48]. Battery collection and recycling therefore are important topics for the EU since a long time. More recently, however, the attention for batteries has substantially increased because of their storage capacity required for balancing a low-carbon electricity grid and for powering an increasing share of electric vehicles in the EU transport system.

In this study only Li-ion technology has been analysed due to its currently dominant market position with regard to performance characteristics and maturity. This section presents possible energy technology dependence mitigation measures for the two critical dependencies found in the Task 4 assessment of the battery energy storage sector: cobalt and cells. The outcomes of the Task 4 analysis are summarized in Table 2-11.

Key conclusions from the task 4 report were:

- Raw cobalt is a critical dependency for the EU battery energy storage sector and presents a key issue due to concerns about mining operations in the Democratic Republic of the Congo (DRC);
- Refined cobalt is not a critical dependency but maintaining the EU industry is of strategic importance;

[47] https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf
[48] http://ec.europa.eu/environment/waste/batteries/index.htm

- Battery cells are a critical dependency but with a relatively low risk. Nevertheless, the EU lags behind in battery cell manufacturing capacities and capabilities but has sufficient suppliers to choose from;
- Battery recycling can (and should) become a strategic part of the value chain for the EU;
- Breakthrough innovations may radically alter dependencies.

The recycling of in particular household batteries has been regulated in the EU already since 2006 in the EU batteries directive[49]. The Directive, which is currently evaluated, prohibits the marketing of batteries containing some hazardous substances, defines measures to establish schemes aiming at high level of collection and recycling, and fixes targets for collection and recycling activities. The Directive also sets out provisions on labelling of batteries and their removability from equipment and sets out conditions to improve the environmental performance of all operators involved in the life cycle of batteries and accumulators.

Battery energy storage now also receives much attention as an important topic for **EUindustrial competitiveness**. "Europe must produce its own batteries for electric cars to avoid crashing out of the race with the United States and China"[50], European Commission Vice-President in charge of energy Maros Sefcovic stated already in 2017. According to the Commissioner, just like in the 1970s, when aerospace firms from across Europe joined forces to face down American competitor Boeing, "an Airbus for batteries," would be required[51]. As a concrete policy response, in 2017 the European Battery Alliance[52] was launched and there are also firm plans in place to develop an ETIP for Batteries. The network activities are supported by actions outlined in the implementation plan on batteries of the EU Strategic Action Plan (SAP)[53]. It outlines five flagship activities to promote EU leadership in battery energy storage technologies: (1) Advanced materials for batteries; (2) Eco-efficient production; (3) Development of batteries with fast charging capability; (4) Second-use of electric vehicle batteries; (5) High yield recycling.
The energy technology dependence mitigation measures already in place relating to **security of supply** are mostly covered by the EU RMI, as well as some specific projects such as the EU STRADE initiative[54]. A report specifically focused on the Raw Materials for Battery Applications was additionally published in May 2018[55]. The report highlights the need to boost knowledge on battery raw materials, as well as stimulating primary and secondary production of battery materials in the EU while also ensuring access to raw materials from global markets.

Table 2-11 Summary of detailed assessment on dependencies for battery energy storage*)

Dependency	Import share	Market concentration (CR4 Country)	Political risk	Ease of market entry	Availability of substitutes	Competitiveness trend
Raw Cobalt	>99%	72%	High	Low	Low	Not applicable

[49] 2006/66/EC
[50] https://phys.org/news/2017-09-eu-commission-airbus-batteries.html
[51] https://phys.org/news/2017-09-eu-commission-airbus-batteries.html
[52] See https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en
[53] See https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/com20180293-annex2_en.pdf
[54] http://stradeproject.eu/index.php?id=3
[55] See https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/swd20180245.pdf

Refined Cobalt	32%	71%	Low	Low	Low	Not available
Battery Cells	High	95%	Low	Low	Medium	Stable

** See Task 4 for exact definition of judgements 'low', 'medium', 'high'*

2.4.1 Dependency 1: Cobalt

Cobalt is a raw material essential for the cathodes used in battery cells. As such, it presents a critical dependency for battery energy storage technology. In 2017, batteries comprised 46% of total cobalt consumption, underlining significant growth since 2013 when this consumption was just 30%. The Democratic Republic of the Congo (DRC) is a major global supplier of cobalt, accounting for 64% of the global market. Dependency on countries like the DRC presents additional supply chain risks, including complicity in human rights violations, which makes cobalt a problematic raw material. Although substantial cobalt is refined in the EU (66% of EU supply of refined cobalt is produced in Finland[56]), currently there are no viable cobalt resources and the raw material is imported from the DRC as well as from Russia. More recently, the largest cobalt mine in the DRC had to temporarily stop production when too high uranium shares in the ores were found, which might affect DRC exports as well as world market prices for cobalt in 2019[57].

- **Existing energy technology dependence mitigation measures**

Cobalt **mining** does not currently take place in the EU. However, EU raw materials policy is firmly in place and is already receiving substantial attention at the EU level, most comprehensively through the Raw Materials Initiative (RMI), with its three pillars supply from global markets, supply from European sources and resource efficiency. Furthermore, although cobalt has not yet been considered in the regulation itself, the EU Conflict Minerals Regulation ensures attention to potential supply chain risks. **Substitution** options have also already been considered, although not many have yet reached the market (LiFePO4 is one example that has[58]). Some Asian producers have considered nickel top-ups in lithium-ion battery production to reduce the amount of cobalt required[59]. Several companies (including Tesla) are also investing in alternative chemistries in their supply chain to minimise the need for cobalt[60], such as LiFePO4[61], Li-S[62] and Li-air[63]. EU-based battery **recycling** has to follow the EU batteries directive, with main companies in Belgium, Germany, France and Switzerland. The current evaluation also opens up possibilities to examine what possibilities there are to stimulate cobalt recycling in the future, such as deposit refund approaches or extended producer responsibility. Finally, **stockpiling** of raw materials (particularly rare earth elements) has been implemented at the supply side in China, but not at the demand side in Europe.

[56] See http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_de
[57] https://www.ft.com/content/07af8226-e1d9-11e8-8e70-5e22a430c1ad
[58] See http://www.europa-batteries.com/en/gamme-36.html
[59] Reuters (2017). Asian battery makers eye nickel top-up as cobalt price bites. https://www.reuters.com/article/us-southkorea-battery-cobalt/asian-battery-makers-eye-nickel-top-up-as-cobalt-price-bites-idUSKBN1AJ0S8
[60] See https://www.bloomberg.com/news/articles/2018-05-02/tesla-supercharging-its-model-3-means-less-cobalt-more-nickel
[61] See http://www.europa-batteries.com/en/gamme-36.html
[62] See http://www.aliseproject.com/li-s-batteries/
[63] See https://www.sciencedirect.com/science/article/pii/S1369702113004586

Table 2-12 Existing EU energy technology dependence mitigation policies for cobalt

EU industrial competitiveness only	EU industrial competitiveness and security of supply	Security of supply only – preventive policies	Security of supply only - crisis management
○ Demand support, price measures, subsidies, taxation, standard setting ○ Trade measures, export support	○ EU-based RD&I for substitution ○ EU-based assembly and production ○ EU-based recycling facilities ○ Increased efficiency / produce for re-use ○ Improving EU access to global markets	○ EU-based primary materials production ○ Diversification of countries of origin	○ Emergency stocks ○ Diversity of energy sources, flexible infrastructures ○ Crisis preparation plans

Green: already sufficient policy action/ no further action recommended Yellow: additional policy action possible; Red: additional policy action recommended; Black: not applicable/not recommended

- **Possible additional measures**

Increasing **EU primary materials production** would bring cobalt supplies under better EU control in terms of both prices and supply chain integrity[64]. However, expanding mining in the EU faces significant pressures particularly with regard to stakeholder opposition and limitations presented by environmental regulations. Opening new mines is highly capital intensive and requires specific know-how, resulting in a significant barrier to entry. Stimulating the growth of EU-based cobalt mining would nevertheless help to avoid the reputational complications of supply chains being associated with the DRC[65]. Increasing EU primary materials production therefore requires public sector attention to expanding the knowledge base for EU based mining and reducing entry barriers for new EU-based raw materials production that fits within environmental obligations.

Substitution options for Cobalt are already under investigation, with several companies investing in research, but have not yet reached the market. These RD&I efforts are increasingly focused on developing non-lithium battery options for e.g. electric vehicles and large-scale energy storage and this should continue to receive public sector support and stimulation. Options include nickel-based batteries[66] and bromine-based applications for storage are also being explored.

Improving access to markets and **diversification of countries of origin** is only an option if information about proven cobalt reserves worldwide is sufficiently available. Improved information sharing between the EU and other governments (e.g. US) on global reserves knowledge therefore is required to improve access and diversification. As part of

[64] http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_nl
[65] http://www.umicore.com/en/cases/sustainable-procurement-framework-for-cobalt
[66] See http://e-stonebatteries.com/web/

this measure, it may be useful to assess the benefits of acquiring physical mining assets outside the EU, something that for instance Germany and Japan are already active in[67]. Furthermore, environmental and (child) labour standards for cobalt imported from DRC similar to those in the EU's Conflict Minerals Regulation (now only aiming at tin, tungsten, tantalum and gold)[68] or in the OECD 'Due Diligence Guidance for Responsible Supply Chains from Conflict-Affected and High-Risk Areas'[69] could influence raw materials streams from the DRC – thereby also opening possibilities for diversification of countries of origin. Stimulating activities under the European Partnership for Responsible Minerals could also be a means to improve exploration conditions in other countries and at the same time increase transparency of resource flows[70].

As explored in task 4, Li-ion **battery recycling** can become a strategic part of the value chain for the EU and important efforts in this direction are driven by current policy[71]. Due to high economic costs, the EU battery recycling sector is not yet sufficiently developed to cover increasing needs for collection and recycling in the future[72]. Recycling activities already envisaged in the SET implementation plan for batteries include reversed logistics including development of low-cost packaging for safer and more efficient recycling, development of an improved reversed logistics business model, dismantling of industrial batteries prior to recycling, robust scaling up of metallurgical or chemical processes for recycling and designing cells for ease of disassembly and recyclability[73].

Whereas the decision to build **emergency stocks** of cobalt would be a political one, consideration of the processing status of the stockpiled cobalt (e.g. refined or raw) and its proximity to battery production facilities would be more technical in nature. Stockpiling of raw materials has been done in other countries, for example in the USA to serve the defence sector.

Possible additional mitigation measures to reduce cobalt dependencies

Technology leadership and preventive policies

- Further build on the initiatives to support battery manufacturing, fast charge, second use and recycling already envisaged under the SET battery implementation plan and the European Battery Alliance initiative in order to create an 'Airbus-like' joint industry effort towards an EU based battery industry;
- Step up EU funding for the development of alternatives to the current use of cobalt in batteries;
- Stimulate EU incentives for and investment in battery recycling industry to avoid future dependency on other regions for battery recycling, thereby possibly considering deposit refund approaches or extended producer responsibility schemes;
- Ensure specific coverage of recycling of cobalt from Li-ion batteries in the ongoing evaluation of the Batteries Directive;

Prevention only

- Investigate economic, socially and environmentally sustainable approaches to expanding mineral

[67] Personal Communication, European Commission, 2018
[68] http://ec.europa.eu/trade/policy/in-focus/conflict-minerals-regulation/regulation-explained/
[69] OECD (2013) Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas, Paris
[70] https://europeanpartnership-responsibleminerals.eu/
[71] See https://journals.uic.edu/ojs/index.php/JUR/article/download/7546/6038
[72] Personal Communication, European Commission, 2018
[73] EC (2017) SET implementation plan batteries, https://setis.ec.europa.eu/actions-towards-implementing-integrated-set-plan/implementation-plans

sources exploration in other countries, thereby using for cobalt similar import requirements as for the minerals in the EU's Conflict Minerals Regulation or in the OECD Due Diligence Guidance; ○ Improve the collaboration between the EU and other regions (e.g. the US) on sharing knowledge regarding mapping raw materials reserves; **Crisis management and containment** ○ Consider stockpiling of cobalt as an ultimate option to reduce current dependencies;

2.4.2 Dependency 2: Cells

Cells are a critical component for battery energy storage technology that is also addressed by the EU SET implementation plan for batteries and by the European Battery Alliance. Asia, particularly China, South Korea and Japan are current major suppliers of battery cells to the EU, in line with since they have relatively low manufacturing costs and have a domestic market for, or are situated close to, the raw constituent materials. The only significant battery cell manufacturer in Europe at this moment is Leclanché in Switzerland.

- **Existing energy technology dependence mitigation measure**

New cathode/cell production plants are currently being erected in Europe (e.g. Samsung SDI[74] in Hungary, SK Innovations[75] also in Hungary, LG[76] in Poland and Northvolt[77] in Sweden). Umicore has announced plans to develop a cathode material production plant in Poland[78]. A further boost to EU based battery cell production, including substitution options for current raw materials dependencies and stepping up recycling is envisaged under the five flagship activities of the SET implementation plan.

Table 2-13 Existing EU energy technology dependence mitigation policies for battery cells

EU industrial competitiveness only	EU industrial competitiveness and security of supply	Security of supply only – preventive policies	Security of supply only - crisis management
○ Demand support, price measures, subsidies, taxation, standard setting ○ Trade measures, export support	○ EU-based RD&I for substitution ○ EU-based assembly and production ○ EU-based recycling facilities ○ Increased efficiency / produce for re-use ○ Improving EU access to global markets	○ EU-based primary materials production ○ Diversification of countries of origin	○ Emergency stocks ○ Diversity of energy sources, flexible infrastructures ○ Crisis preparation plans

Green: already sufficient policy action/ no further action recommended Yellow: additional policy action possible; Red: additional policy action recommended; Black: not applicable/not recommended

[74] http://www.samsungsdi.com/sdi-news/1642.html?idx=1642
[75] https://electrek.co/2017/11/30/sk-innovation-electric-car-battery-gigafactory-hungary/
[76] https://pushevs.com/2018/03/12/lg-chem-to-triple-ev-battery-production-in-poland/
[77] https://electrek.co/2018/04/27/northvolt-construction-first-phase-planned-battery-gigafactory/
[78] http://www.umicore.com/en/media/press/201800601rbmeuropeanplanten

- **Possible additional measures**

Despite many activities already being envisaged to increase EU based battery cell production, significant barriers to new EU entrants to the cell manufacturing market remain. These include notably high start-up capital requirements, intellectual property (particularly patents) and economies of scale[79]. Access to start-up finance and protection of property rights therefore require sufficient attention in the foreseen activities to stimulate EU-based production. Standardisation of cell production, re-use and recycling could also contribute to economies of scale that are required for a successful growth of the EU battery industry. This also holds for ensuring optimal **reuse** and **recycling** that is a prerequisite for ensuring the overall sustainability of the battery sector. Financial support is required to develop more specialist battery recycling research centres such as the Munster University 'MEET' centre[80].

Possible additional mitigation measures to reduce cell dependencies

Technology leadership and preventive policies

- In support of already foreseen actions to boost the EU battery cell industry, ensuring sufficient access to finance for new parties entering the market in production and recycling should also be assured;
- Attention needs to be paid to intellectual property rights for battery innovations from EU battery RD&I in order to allow for successful business models of innovative battery start-ups;
- Standardisation of EU cell production and recycling practices should be considered as a precondition for developing economies of scale for a growing EU battery industry;

Prevention only: none recommended

[79] Trinomics (2018) project interviews with industry representatives, personal communication
[80] https://www.unimuenster.de/MEET/en/index.html

3 Policy recommendations and actions

This report has looked into detailed dependencies for three low-carbon energy sectors that are considered particularly relevant for energy technology dependency mitigation: wind, solar PV and battery energy storage. These are summarised in Annex C of this report.

Using the insights of this detailed analysis, the final chapter of this report will now zoom out to the wider context of EU low-carbon energy policies and the role of energy technology dependency mitigation policies herein. These policies were defined in the report to consist of energy security of supply policies on one hand, and of EU industrial competitiveness policies on the other hand. It was discussed that policy measures directed at either of the two energy policy topics do partly overlap (Figure 2-1).

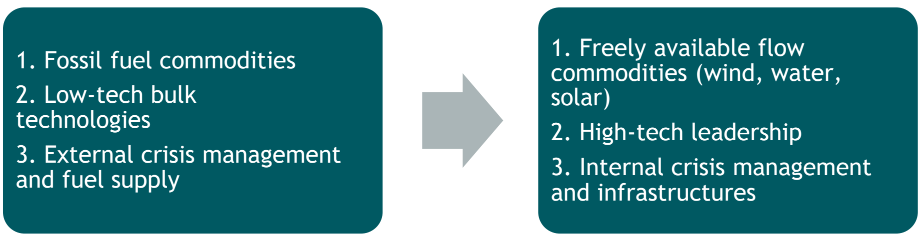
The chapter first discusses general conclusions and design principles for future low-carbon energy technology dependence mitigation policies. Section 3.1 goes into on the role of EU industry policy and section 3.2 discusses the role of the value chain in these policies. Specific policy measures that can combine boosting EU industrial competitiveness and security of supply are subsequently outlined in section 3.3, whereas measures that are likely to improve security of supply only are the topic of section 3.4. Finally, the chapter discusses who needs to do what to realise the suggested actions (Section 3.5), before ending with an overall summary of main conclusions from this study (section 3.6).

3.1 An increasing role for EU industry policies in energy technology dependence mitigation

Three main trends are likely to set the scene for future low-carbon energy technology dependency mitigation policies when comparing them to past separate security of supply and industrial competitiveness policies: a gradual replacement of imported fossil fuels by locally available flow commodities like hydro, wind and solar power, a shift from bulk and relatively low-tech to high-tech energy supply applications, and a shift in policy attention from crisis management to preventive policies (Figure 3-1).

Figure 3-1 Changing policy priorities from fossil fuel to low-carbon technology dependency (source: own assessment)

Fossil fuel dependency **Low-carbon technology**



dependency

From fossil fuels to flow commodities

Rather than assuring the imports of bulk fossil fuel commodities, EU energy technology dependence mitigation policies in the decades to come, will have to provide the conditions for continuous innovation, diversification and expansion of domestic low-carbon energy technologies that can optimally harvest 'flow commodities' like hydro, wind and solar power. Hence, the nature of EU energy security of supply will gradually change from securing access to fossil fuels and transit routes outside the EU, to deployment of low-carbon energy technologies and embedded materials that are partly imported and partly produced within the EU itself. The proper functioning of internal and international markets will therefore be essential to make sure that such technologies raw materials and technologies can be produced within the EU or can be imported at all times against affordable market prices.

From low-tech to high-tech

Previous energy security of supply policies have primarily focused on two bulk commodities: petroleum and gas. The biggest part of their processing and refinery for energy use is based on technologies that have already been established and consolidated several decades ago. On the contrary, low-carbon energy technologies that 'harvest' and process flow commodities are still very much under development. Further refinement and consolidation of these technologies for large-scale bulk application in the future will be required. High-tech skills will be required to develop such tailor-made applications, while at the same time also other, lower-tech job opportunities need to be developed in order to contribute to future employment in the EU low-carbon energy sector.

From crisis management to preventive policies

The change from bulk imported energy sources towards high-tech applications of flow commodities will also imply that any sudden technology supply disruption will no longer result in acute energy shortages in the EU (within days or weeks), as was the case in past oil and gas crises. Rather, external commodity supply disruptions will cause an interruption in the process of installing new low-carbon energy technologies, with possible longer-term consequences for energy security of supply (in terms of months and years). Sudden disruptions might rather arise caused by developments internal to the EU, in particular terrorist or foreign attacks against EU internal electricity, (bio- and hydrogen) gas and ICT-infrastructures. Future crisis management measures addressing energy technology dependence therefore need to be rather directed at EU internal infrastructures than at external dependency risks. A shift towards more preventive energy dependency policies in the future therefore is likely.

Overall, these changes are likely to result in **a far larger role of EU industry policies in mitigating energy technology dependence than in the past.** In this report, wind, solar PV and battery energy storage were studied as three energy industry subsectors that might be particularly affected by future energy dependencies. It has been outlined that the positions of these three subsectors are quite different. Whereas in wind, the EU industry still has a substantial position and in solar PV, most of the market share has been lost to foreign suppliers, the battery energy storage sector represents a relatively new opportunity to gain EU market share that now has full policy attention within the EU. Despite all differences between these energy industry subsectors, the main overall conclusion to be drawn for all three sectors is the same: <u>the current major process of change towards a low-carbon energy sector in the EU and elsewhere provides an unique opportunity for the EU energy industry to obtain a leading position in future energy markets that can, at the same time, substantially contribute to mitigating future energy technology dependencies</u>.

3.2 The circular economy as a design principle for energy technology dependence mitigation

This study has investigated integral value chains as an object of energy dependencies and their mitigation. Raw materials, components and pre-assembly, on-site integration and installation, and decommissioning were distinguished as the main general elements of these value chains. Table 3-1 shows the main critical dependencies found, set out against these value chain elements.

Table 3-1 Critical energy dependencies and the value chain (own assessment)

	Raw materials	Components and pre-assembly	On-site integration and installation	Decommissioning
Critical dependencies	- Neodymium and dysprosium (wind) - Cobalt (batteries)	- Insulation materials for high-voltage cables (wind) - Fibreglass for wind turbine blades (wind) - Insulated Gate Bipolar Transistors (wind) - PV cells and modules (solar PV) - Inverters (solar PV) -Battery cells (battery energy storage)	- None identified	- None identified

From the above table, it is clear that, while it is still very important to take into consideration the dependency factor of raw materials, the integrated assessment of security of supply and EU industrial competitiveness also shows that **many future low-carbon energy technology dependencies are likely to be found not only in the raw materials, but also in the components and pre-assembly stage**.

No critical dependencies are found for the on-site integration and decommissioning stages. However, these stages of the value chain play a very important role when looking into proposed policy solutions for the identified energy dependencies (sections 3.3 and 3.4). For solar PV cells and modules, for instance, fostering a market for on-site integration and installation is likely to be an important element for a renaissance of the European PV industry. Further, setting up appropriate collection, re-use and recycling facilities not only for raw materials but also for components is likely to substantially contribute to mitigating future energy dependencies. Here, a crucial difference with fossil fuel energy dependency becomes apparent: whereas fossil fuels are burnt and are therefore single-use by nature, all critical components in a low-carbon energy sector can in principle be re-used or recycled. **Stimulating a circular economy with as high as possible re-use and recycling rates is therefore a crucial design principle for mitigating future energy dependencies.**

3.3 Measures to mitigate energy dependency and boost EU energy technology industrial competitiveness

In the previous chapter, several concrete energy technology dependence mitigation measures were recommended for the wind, solar PV and battery energy storage sectors. These measures are integrated here in recommendations for a wider strategy to mitigate future low-carbon energy dependencies. Such an integral strategy would have to consist of measures that assure a regular combined assessment of security of supply and EU industrial competitiveness, targeted RD&I measures, demand-side measures, supply-side measures and trade measures.

In short, we recommend to develop an **integrated low-carbon energy technology dependency mitigation strategy** consisting of:

- **Foresight:** Making a strategic and forward-looking energy technology dependence assessment as carried out in this study part of the already existing reporting obligations for the EU under the Better Regulation Guideline;

- **RD&I measures:** Focusing future Horizon Europe calls as well as SET Implementation plans on energy dependency RD&I in all value chain phases, particularly also on on-site integration, re-use and recycling, as well as on upscaling and EU industry development and employment aspects of innovations;

- **Demand-side measures:** Contributing to a stable home market for EU-based energy technologies by more strongly promoting and branding 'made in Europe' low-carbon energy technology;

- **Supply-side measures:** Expanding tailored clustering support and market differentiation per industry segment building on the examples of the European Battery Alliance and the Energy Technology & Innovation Platforms;

- **Trade measures:** Stimulating the development of open energy technology markets and multilateral trade agreements and addressing existing public resistance against these;

- **Other dependency mitigation measures (without benefits for EU industrial competitiveness):** Stimulating transparency of resource flows and promoting environmentally and socially responsible mining inside and outside the EU as well as strategic assessment on an EU level of Member States' contingency planning for future energy dependency crises.

3.3.1 Integrated energy dependency assessment and the Better Regulation Guidelines

In this study, a new methodology for strategic integrated assessment of energy technology dependence mitigation was developed and applied. In short, it consisted of a new definition of critical energy technology dependencies to also comprise EU industrial competitiveness policies, a broad-brush analysis of a wide range of energy technologies, a detailed analysis of a limited number of selected technologies and an identification of existing policies with whom additional measures would need to be matched and merged to form a new integrated energy technology mitigation strategy.

In order to be effective, such an assessment should be repeated regularly as low-carbon energy markets are changing rapidly. A bi-yearly frequency probably could combine the needs for regular updates with practical applicability of such an assessment. The assessment should not introduce additional administrative burdens to individual Member States and should be in line with the EU Energy Union Governance Regulation[81] and the Commission's Better Regulation Guidelines[82].

The Better Regulation Guidelines define exactly the process of an Impact Assessment as envisaged here[83]. In addition, the EU Energy Governance Regulation already requires Member States to report, in an integrated national energy and climate plan but separately, on the five pillars of the Energy Union Strategy: energy security, energy market, energy efficiency, decarbonisation and research, innovation and competitiveness (Art 3.). Based on these plans, the Commission has to make a bi-yearly aggregate assessment of progress and policy response to ensure Union targets achievement (Art. 25). It is therefore recommended that:

- A specific question will be added in Tool 21 of the better regulation package.[84] We propose to add in step 2 of tool 21, a question related to EU industrial competitiveness and EU security of supply. The question to add could be 'In which way does the proposed intervention potentially affect the EU industrial competitiveness (in the different parts of the value chain) and the EU security of supply?

3.3.2 RD&I measures: stimulating targeted research and innovation in the whole value chain

RD&I was part of all detailed recommendations for the various critical dependencies in the wind, solar PV and battery energy storage sectors and therefore should be considered a very important part of a successful strategy to mitigate energy technology dependence. From the detailed analysis, it is concluded that energy dependency RD&I should be specifically directed at finding substitutes for raw materials and improving efficiencies of components and end-products.

However, next to these more traditional search directions for RD&I, also investigation of re-use and recycling technologies should be stepped up in order to contribute to mitigating future energy technology dependence by closing the loops towards a circular economy. Next to fundamental RD&I on a low-TRL, focusing on materials science, also RD&I on higher TRLs is required that focuses on on-site integration and installation. In this way, a sound home market for low-carbon energy technology applications in the EU can be developed that is less prone to low-cost competition from abroad as was the EU PV sector in the past. In all application-directed RD&I at higher TRLs, attention should be paid to employment aspects of technology that is developed as well as to the social aspects of a large-scale energy transition. It should preferably comprise high-tech as well as low-tech employment opportunities in order to foster employment opportunities for all Europeans. It is therefore recommended that

- **Directions for RD&I targeting energy technology dependency should be set in the Terms of Reference of individual calls under the future Horizon**

[81] COM(2016) 759 final/2, 30.11.2016
[82] https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how/better-regulation-guidelines-and-toolbox_en
[83] EC (2015) Better Regulation Guidelines, chapter 3: Impact Assessment
[84] (https://ec.europa.eu/info/sites/info/files/file_import/better-regulation-toolbox-21_en_0.pdf

Europe programme, as well as in updates of the SET-plan implementation plans of the various technologies that have been published recently.

3.3.3 *Demand-side measures: contributing to a stable EU home market by branding 'made in Europe' energy technologies*

As outlined in the framework for analysis of this report (section 2.1), stimulating demand for low-carbon energy technologies only, without at the same time also stimulating supply, does not contribute to mitigate security of supply aspects of energy technology dependence: foreign suppliers will be very much interested to close any supply-gaps caused by increasing demand within the EU. Therefore, no specific demand-side measures were identified to mitigate energy technology dependencies in the detailed analysis of the wind, solar PV and battery energy storage sectors. Nevertheless, on the level of EU energy technology as a whole, general demand-side measures could make sense. Reason is that without a stable home market, EU-suppliers are not very likely to be able to develop a global market share either.

Basic conditions for a creating a home market for low-carbon energy technologies in the EU are already in place. These consist in particular of setting RES deployment targets, feed-in tariffs and generic subsidies for renewables. There are also several existing measures to reduce price differentials between fossil and low-carbon energy technologies, such as abolishing fossil subsidies. These could be further stepped up. What is lacking so far, however, is a specific consumer demand for EU-produced technologies. Neither is it made easy for consumers to identify and choose specific EU-produced energy technology, similar to equivalent Member State brands promoted by national trade councils. It is therefore in particular recommended to

- **Stimulate branding 'made in Europe' energy technology in order to facilitate a deliberate choice of consumers for energy technologies that are produced within the EU.**

3.3.4 *Supply-side measures: tailored clustering support and market differentiation per industry segment*

Dependencies can also be mitigated by supply-side measures. Stimulation of EU-based production, assembly and production processes, as well as improved efficiency of such production processes and higher recycling levels can all contribute to mitigating future energy technology dependencies. In particular recycling (of e.g. batteries, wind turbines or PV modules and cells) thereby seems a still relatively underdeveloped area due to the early stage of development of many low-carbon energy technologies.

Cost levels of EU suppliers of low-carbon energy technologies are often higher than those of competitors abroad, due to e.g. higher labour costs in the EU. Policies that influence such cost levels therefore could be applied but could involve high costs to the EU and might also conflict with state aid rules. Other supply-side measures that benefit EU industrial competitiveness as well as security of supply could involve the promotion of industrial clustering and making available sufficient investment capital for the needs of industry and SME. This could involve developing more 'Airbus-like' technology spearheads such as the European Battery Alliance as an expansion of the already existing Energy Technology and

Innovation Platforms for various technologies. In the case of batteries, also standard setting could help to develop one internal market, with unified requirements for battery energy storage specifications.

The analysis of the solar PV market further revealed that the development of sheltered, location-based applications with added value in quality and design might be a way to develop successful niche-markets. For a successful expansion of such markets it might be required to bring together parties that do not automatically find each other, such as in the case of solar PV the construction, ICT and solar panel and module industry. It is therefore recommended to

- **Stimulate cross-sectoral clustering and network building between energy technologies in order to facilitate development of differentiated markets within the EU that fulfil specific requirements and standards of the European home market.**

3.3.5 Trade measures: building public support for open markets in times of trade disputes

Dependency on, in particular, imports from China, has shown to be a very important issue in the analysis of the wind, solar PV and battery energy storage markets. Previously import protection measures have been taken in the solar PV market in order to prevent 'dumping', but these measures have been lifted again. Meanwhile, however, other trade disputes (in particular US – China) have emerged that seem to signal a time of increasing market protection and less focus on free trade.

The analysis of this report nevertheless suggests that, rather than through import protection as an ultimate resort measure, EU energy technology dependencies could be mitigated through assuring access to global markets and through promoting trade with other suppliers by for instance bilateral trade agreements. At the same time there also exists substantial public resistance in the EU against global trade, as shown for instance in the many protests against the planned EU-US (TTIP) free trade agreement. This often goes together with preferences for local markets and locally produced goods and services. A transparent public discussion about how to combine the benefits of free trade with branding local technology therefore would be required to address public concerns about trade issues. It is recommended to

- **Continue ongoing efforts on bilateral free trade agreements (e.g. with Australia) and simultaneously promote public discussion on how to combine global trade with branding of locally produced goods and services.**

3.4 Other measures to mitigate energy technology dependence

Energy technology dependence mitigation measures that are less likely to have benefits for EU industrial competitiveness policies consist of preventive as well as of crisis management measures. A possible preventive measure with less clear benefits for EU low-carbon energy industry is the stimulation of EU-based mining, as is currently done under the second pillar of the EU Raw Materials Initiative. While some reserves of critical raw materials on the EU territory exist, exploration of these often is difficult because of public resistance, cost and environmental considerations. Also, a higher involvement of EU companies in mining activities elsewhere could be pursued so that a continuous supply of raw materials for high-tech applications in the EU can be better controlled throughout the whole supply chain. In that case the EU should also see to it that environmental and human rights conditions in the extraction countries are guaranteed, for instance through the European Partnership for Responsible Minerals[85].

Crisis management measures form a final component of an integral energy technology dependence mitigation strategy, although in a future low-carbon sector the risk of sudden supply disruptions that create immediate energy shortages within the EU is likely to be far lower than in the existing fossil dominated energy sector. Stockpiling of raw materials, now a common measure for oil in the fossil-based energy sector, therefore will become a measure of very last resort only. On the other hand, the importance of improving the resilience of EU electricity, gas and ICT-infrastructures to intentional disruptions will increase. Existing crisis management and containment planning therefore should be adapted accordingly. Reporting obligations in this respect already consist in the Member State Integrated national energy and climate plans required under the Better Regulation Guideline (Art. 4)[86]. It is therefore recommended to

- **Stimulate transparency of resource flows, environmentally and socially responsible mining of critical raw materials inside and outside the EU, as well as strategic assessment of Member State crisis management plans on an EU level.**

3.5 Policy coordination and action

As has been shown in the previous chapters, many actors and networks are already involved in the mitigation of energy technology dependence by means of a large variety of policy measures. For the three investigated markets, there are for instance the Energy Technology & Innovation Platforms for wind and solar PV as well as the European Battery Alliance that coordinate stakeholder action at European level. Next to that, many activities take place on a national level, including for instance Member State policy action as well as the coordination of national industry networks and platforms. Regarding raw materials, the Raw Materials Initiative unites a large number of actors in actions to assure access to resources in third countries, foster supply from European sources and boost resource efficiency. The policy coordination and action outlined here therefore only applies to the supplementary actions proposed in the above 'integrated low-carbon energy technology dependence mitigation strategy'.

Action 1: Strategic energy technology dependence foresight

Integrated strategic energy technology dependence foresight as carried out in this study is an EU internal strategic action that serves to inform the DGs about trends and changes regarding critical energy dependencies. The action can be carried out as an Impact Assessment as outlined in the Better Regulation Guidelines and could be based on existing reporting obligations under the EU Energy Union Governance Regulation. It is relevant to

[85] https://europeanpartnership-responsibleminerals.eu/

[86] COM(2016) 759 final/2, 30.11.2016

most DGs and can be best coordinated by the DG that is (together with DG CLIMA) the main responsible for reporting under the governance of the Energy Union, DG ENER.

Action 2: Targeted energy dependency RD&I and upscaling

Addressing specific RD&I actions for mitigating energy technology dependence mitigation, such as more focus on the critical raw materials identified, on opportunities for improved re-use and recycling in general and on upscaling that considers product differentiation into sheltered (e.g. building-integrated) markets with wider employment impacts, could best be done by DG RTD. In its formulation of specific terms of reference for such targeted RD&I it should consult the internal market and employment related DGs as well as external organisations that are relevant for getting the proper understanding for RD&I conditions required, such as re-use and recycling organisations and employers and trade unions.

Action 3: Branding 'made in Europe' energy technology

Branding 'made in Europe' energy technology is an action that could help to generate a stable home market for energy technologies produced in the EU, next to all actions to stimulate an EU low-carbon energy technology market that are already in place. In times of Brexit and of many Member States where nationalistic movements and aspirations seem to gain political power this has to be considered as a very sensitive action that can only be carried out as part of a much broader 'EU renaissance' campaign that has to be initiated on the highest EU level. The Secretariat General should therefore coordinate such a wider campaign after political consultation of the MS Governments. The campaign itself should have involvement of several energy and trade related DGs and could be led on an executive level by DG COMM together with trade organisations on an MS level.

Action 4: Airbus-like industry coalitions and networking

The European Battery Alliance is considered by the Commission to be an 'Airbus-like' initiative[87] that brings together all relevant parties in this very important market for EU industrial competitiveness. It is the aim of Vice-President for Energy Union Maroš Šefčovic, to establish a full value chain of batteries in Europe, with large-scale battery cells production and Sec. Gen. has the responsibility to coordinate this objective hand in hand with more than 10 different DGs.

In order to stimulate the development of new, differentiated markets that are not only based on cost competition in other energy technologies as well, similar initiatives could be stimulated that bring together parties that do not automatically find each other, e.g. by stimulating intensified interaction between existing ETIPs. Development of such differentiated markets could be stimulated by targeted standard setting that not only contributes to the creation one internal EU market, but also to possibilities for differentiation within this market (e.g. building regulations stimulating integrated solar solutions). The substantial investments required for such major EU industry initiatives and spearheads could only be coordinated on the Secretary General level within the EU, after approval of MS governments. After that, the size of such coalitions would require the involvement of several DGs.

[87] http://europa.eu/rapid/press-release_STATEMENT-17-3861_en.htm

Action 5: Stimulating open markets and addressing public concerns against free trade

Against global trends that seem to indicate coming times of more market protection and trade conflicts, the European Union is still a proponent of reducing global trade barriers. Many multilateral and bilateral actions are already undertaken in this respect, which also help to reduce energy dependencies by improving market access for European companies. These are a topic of external trade and foreign relations, and therefore can be best coordinated by DG TRADE. In order to address growing public concerns against free trade and rising preferences for 'local production' within the EU, a public dialogue on benefits of trade with involvement of DG COMM should be part of energy dependency mitigating external trade stimulation. Responsible trade that pays attention to respecting human rights and environmental conditions in developing countries in which raw materials are mined should be part of such external trade efforts, therefore DG DEVCO and external development organisations should be part of the efforts under this action.

Action 6: Crisis management

Crisis management related to energy technology dependence could be coordinated by DG ENER or Sec. Gen., based on its existing security of supply reporting obligations under the EU Energy Union Governance Regulation. Counter-actions related to infrastructure related energy supply disruptions should be coordinated with internal defence and intelligence organisations. Trade measures such as import tariffs should be coordinated with DG Trade.

3.6 Conclusions

This study has shown that mitigation of energy technology dependence will require new policy approaches compared to previous fossil energy security of supply policies in the years to come. The most prominent of these is probably the increasingly dominant role that EU industrial competitiveness will come to play in mitigating future low-carbon energy technology dependencies. While many actions that contribute to mitigating such dependencies are already now undertaken under a large variety of headings and responsibilities, what is still lacking so far is a strategic foresight and coordinated action towards mitigation of low-carbon energy technology dependence. We hope that this study has been an important step towards such a more integrated view and strategy for successful mitigation of low-carbon energy technology dependence on an EU level in the future.

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Annex A - Existing mitigation measures to reduce technology dependencies

This chapter explores existing mitigation measures in several policy areas that might be useful as well for mitigating potential new low-carbon energy dependencies. The policy areas and sectors analysed are:

- The EU Raw Materials Initiative;
- Existing European fossil energy security of supply policies;
- Wind, solar PV and batteries; and
- Defence/aerospace and ICT.

The EU Raw Materials Initiative is analysed because in previous work packages of this research project it was found that many low-carbon energy technology dependencies relate to raw materials. Existing fossil security supply policies are scrutinized to analyse how these policies so far deal with technology dependencies and supply risks. Wind, solar PV and batteries are examined as these low-carbon energy technology areas were found to be particularly prone to new energy technology supply risks in the broad-brush analysis of low-carbon energy technologies carried out in task 3 of this project. Finally, defence, aerospace and ICT are investigated as these sectors have a similar strategic importance as energy and therefore also have to deal with mitigation of supply risks.

First, the current status quo of the selected policy areas will be outlined (Sections 2.1 to 2.4). Section 2.5 will discuss the overall lessons learned from this analysis of existing security of supply mitigation policies.

A.1 Technology leadership/competitiveness

Throughout this study, the existing mitigation measures are assumed as a given both in the area of security of supply and in the area of industrial competitiveness. Policies regarding EU-based technology competitiveness in the low-carbon energy technology sector are already well-developed, most focusing on the objective of achieving competitive advantage and a larger market share in the production of low-carbon energy technology.

Within the context of the wider Renewable Energy Directive,[88] some of the existing mitigation measures that provide a supporting framework for all technologies include the overarching EU Clean Energy Industrial Competitiveness and Innovation Forum launched in January 2018 by the EC. This forms part of the Clean Energy for All package and provides a forum for meetings and discussions on the future of low-carbon energy technologies – in particular, how to reinforce competitiveness throughout the value chain[89]. Specific objectives of this forum include to support EU's objective to become a global leader in renewables; to track EU competitiveness through Key Performance Indicators, recognising global market

[88] See https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive
[89] See https://ec.europa.eu/info/news/launch-eu-clean-energy-industrial-competitiveness-and-innovation-forum-renewables-2018-jan-08_en

opportunities; to highlight barriers and opportunities related to trade and global markets[90]. EU Industrial Policy[91] and EU Competition Law[92] additionally provide the framework within which technology developments take place. The Strategic Energy Technology Plan (SET-Plan) is also in place, strategically focusing innovation efforts in low-carbon energy technologies in the EU[93].

Other mitigation measures are technology-specific. For example, wind-specific strategies have been proposed by WindEurope, including the European Wind Initiative, which forms an important component of SET-Plan. Although there is no direct strategy for the governance of the wind sector set out by the EU, the specific European Technology and Innovation Platform (ETIP) for wind energy provides a vital framework for future developments in this sector[94]. There is no specific EU strategy relating to solar PV, but again there is an ETIP in place also for solar PV, which provides a framework for future developments in this sector[95]. These ETIPs are based on the Renewable Energy Directive (2009/28/EC)[96]. Although batteries currently do not benefit from an ETIP (although there are firm plans in place to develop an ETIP for Batteries, which will provide a further platform for this sector), battery energy storage is an area that has received significant attention in recent years regarding the EU's opportunity to take a leading position in the development of this technology. Battery sector waste management is governed by the Batteries Directive (2006/66/EC) (currently undergoing an evaluation). Battery energy storage also benefits from a targeted strategy through the European Battery Alliance[97] launched in 2017 and the resulting output, the Strategic Action Plan on Batteries (SAP)[98].

A.2 The EU Raw Materials Initiative

Raw materials came high on the political agendas following the rare earth metals supply "crunch" of 2010/11 and the commodity price crash between 2014/15. Currently therefore raw materials policy in the EU is very well developed and there are many examples of policy actions, projects and research. The overarching policy approach for mitigating raw materials dependencies is the **EU Raw Materials Initiative (RMI)**[99], which has the main aim of guaranteeing secure and sustainable raw material supplies. The RMI is implemented through the European Innovation Partnership on Raw Materials (EIP) and through dedicated Horizon 2020 projects (Figure A-1). In some cases, the raw materials have been assessed at the technology-level. For example, a report specifically focused on the Raw Materials for Battery Applications was published in May 2018[100]. The report highlights the need to boost knowledge on battery raw materials, as well as stimulating primary and secondary production of battery materials in the EU while also ensuring access to raw materials from global markets.

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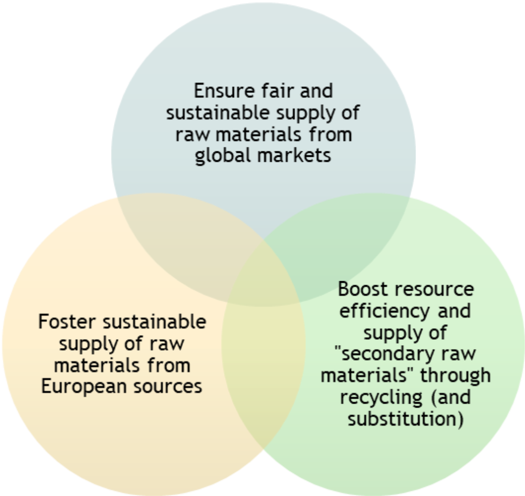
[90] See https://ec.europa.eu/info/news/launch-eu-clean-energy-industrial-competitiveness-and-innovation-forum-renewables-2018-jan-08_en
[91] See https://ec.europa.eu/commission/news/new-industrial-policy-strategy-2017-sep-18_en
[92] See http://ec.europa.eu/competition/sectors/energy/overview_en.html
[93] See https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan
[94] See https://etipwind.eu/
[95] See http://www.etip-pv.eu/homepage.html
[96] See https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive
[97] See https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en
[98] See https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/com20180293-annex2_en.pdf
[99] EC Website (2018). Raw Materials. https://ec.europa.eu/programmes/horizon2020/en/area/raw-materials
[100] See https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/swd20180245.pdf

In this section, we present our assessment of EU raw materials policy efforts based on the three pillars of the Raw Materials Initiative, which also define the subheadings of this section: Section 2.1.1 will discuss ensuring supply of raw materials from global markets, section 2.1.2 is directed at policies for realising the potential of new raw materials extraction within Europe, and section 2.1.3 outlines possibilities for boosting resource efficiency, supply of secondary materials and substitution.

Figure A-1 The 3 pillars of the Raw Materials Initiative (Source: European Commission[101]).



Textbox A-1 The European Innovation Partnership on Raw Materials and Horizon2020

The **European Innovation Partnership on Raw Materials (EIP)** reinforces the RMI by translating its strategic priorities into concrete actions, while also mobilising the stakeholder community for implementation[102]. Realised actions under the EIP include establishing the *European Institute of Innovation and Technology (EIT) section on Raw Materials* (a consortium on knowledge and innovation involving public, private, academic and research entities[103]), establishing the *EU Raw Materials Information System*[104] and the *European Raw Materials Scoreboard*[105].

The 7 priority action areas of the EIP are[106]:

1. Research and innovation coordination;
2. Technologies for primary and secondary raw material production;
3. Substitution of raw materials;
4. Improving Europe's raw materials framework conditions;
5. Improving Europe's waste management framework conditions and excellence;
6. Knowledge, skills and raw materials flows; and,
7. International cooperation.

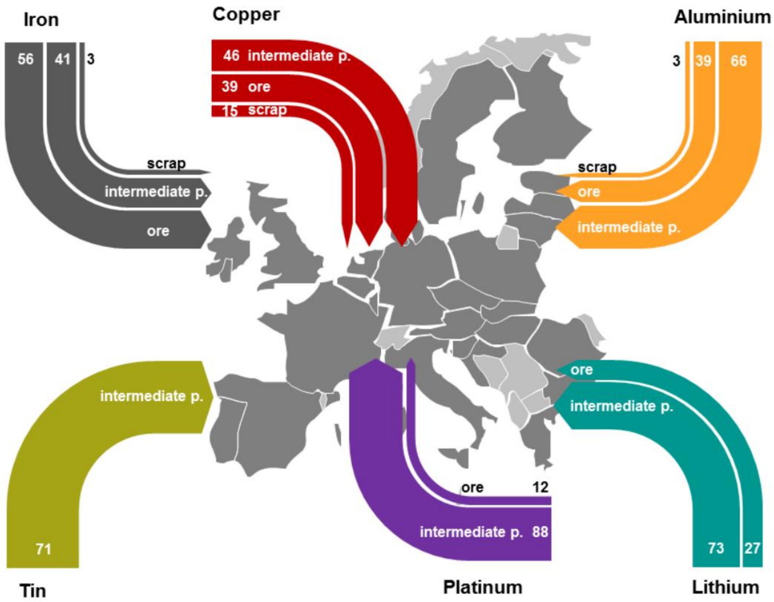
The **European Horizon 2020 programme** has been instrumental in implementing actions of the European Innovation Partnership, including securing €600m for raw materials RD&I projects and initiatives. Several projects on raw materials research and innovation (RD&I) are currently being funded through Horizon 2020 and new projects on the topic of raw materials are also being facilitated through this funding.

[101] EC (2018). Policy and strategy for raw materials. https://ec.europa.eu/growth/sectors/raw-materials/policy-strategy_en
[102] EC Website (2018). The European Innovation Partnership (EIP) on Raw Materials. https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/european-innovation-partnership-eip-raw-materials
[103] EIT Raw Materials (2016). https://eitrawmaterials.eu/about-us/
[104] JRC (2018). Raw materials information system. http://rmis.jrc.ec.europa.eu/
[105] EC (2018). EIP on Raw Materials Monitoring and Evaluation Scheme. https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/eip-raw-materials-monitoring-and-evaluation-scheme
[106] EC (2018). Strategic implementation plan. https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/strategic-implementation-plan-sip-0

Pillar 1: Supply from global markets

The EU imports a large proportion of raw materials (Figure A-2). The three principal methods through which the EU aims to secure supply from global markets are raw materials diplomacy and international cooperation; trade and regulatory policy; and, promoting a sound investment climate in third countries.

Figure A-2 Ores and intermediate products for EU processing industry, import shares (%) for 6 selected metals (Source: STRADE Project, 2017[107]).



Securing supply from global markets: raw materials diplomacy and international cooperation

Diplomacy around raw materials can lead to shared benefits through strategic partnerships and policy dialogues, ultimately reducing raw materials security of supply risks. As such, the Commission has identified reaching out to strategic non-EU partner countries through Raw Materials Diplomacy as part of the first pillar in the EU's Raw Materials Initiative[108].

The Commission maintains regular policy dialogues with the main international raw materials suppliers, such as China, India and the USA, as well as with main other demand centres such as Japan. For example, the Commission engages directly with China to mitigate export duties and reach other bilateral agreements (Textbox A-2). EU Letters of Intent for raw materials have also been signed with Chile, Uruguay, Colombia, Mexico, Peru, Morocco, Tunisia, Egypt and Greenland.

[107] STRADE (2017).EU raw material import flows – acknowledging non-EU environmental and social footprints. http://www.stradeproject.eu/fileadmin/user_upload/pdf/STRADEPolBrf_02-2017_RawMaterialFlows_Mar2017_FINAL.pdf

[108] EC (2018). Raw Materials Diplomacy. http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/international-aspects_en

Textbox A-2 EU-China dialogue

The main modes of engagement with China, one of the EU's most important trading partners, are through the EU-China Summit and the EU-China High Level Economic and Trade Dialogue. The main topics of discussion in 2017 included security, energy cooperation, transport connectivity, agriculture, RD&I, tourism and maritime affairs. Key outcomes include renewal of the EU-China co-funding mechanism for RD&I for 2018-2020, as well as signature of the Work Plan 2017-2018 of the Technical Implementation of the EU-China Roadmap on Energy Cooperation[109].

Specifically, with regard to raw materials, the EU-China Working Group on Raw Materials and the Metals Working Group also present fora for information exchange, cooperation and bilateral agreements. Highly specialised groups also exist, for example the EU-China Steel Contact Group[110].

There are also specific efforts towards joint research, for example Commodity Study Groups in which the European Commission is active. These include the International Study Groups on different metals such as zinc, copper and nickel. These study groups meet regularly to discuss trade, production and exploration trends. Additional collaborative research projects are also funded through Horizon 2020 (Textbox A-3).

Textbox A-3 International research collaboration

The EU has engaged in collaborative research activities with several countries through the Horizon 2020-funded ROMEO initiative, which worked on identifying rare-earth-free magnets, permanent magnets being of particular importance to the offshore wind energy sector. The project involves collaboration with 6 EU Member States, 1 associated country and several large companies pursuing the optimisation of offshore wind farms, in particular improving reliability and reducing costs[111].

Finally, intra-EU cooperation may be important to achieve a unified approach to dealing with raw materials dependencies. Other than regular dialogues, this can also be achieved through the EU's cohesion fund, which supports EU countries whose Gross National Income per capita is lower than 90% of the EU average. Raw materials are explicitly mentioned in the rules for the EU's cohesion fund, particularly within the context of the circular economy[112].

EU trade and regulatory policy

Trade policy is important to ensure and improve EU access to raw materials, ultimately reducing security of supply risks. The Raw Materials Initiative aims to achieve free and transparent raw materials markets and suggests that trade policy should be used in the following ways:

- Elimination of export restrictions through bilateral and multilateral negotiations;
- Free trade agreements;
- Use of dialogue, WTO dispute settlement and Market Access Partnerships to remove trade barriers; and,
- Raise awareness of trade issues in international fora.

[109] EC (2017). EU-China Summit: moving forward with our global partnership. http://europa.eu/rapid/press-release_IP-17-1524_en.htm
[110] http://trade.ec.europa.eu/doclib/press/index.cfm?id=1473
[111] ROMEO (2018). ROMEO Project. https://www.romeoproject.eu/
[112] EC (2018). Cohesion fund. http://ec.europa.eu/regional_policy/en/funding/cohesion-fund/

Successful free trade agreements that gave due consideration to raw materials were carried out with Korea, Singapore, Central America and Vietnam (Textbox A-4). In cases where the EU is unable to achieve desired outcomes through constructive discussions, the World Trade Organisation (WTO) may intervene. For example, in 2014 the WTO ruled against Chinese rare earth elements (REEs) export duties and quotas[113] and in 2016 another case was filed jointly by the EU and the US against China for constraining the supply of 11 raw materials[114].

Many European suppliers have also built a local presence in China as a way of stabilising trade relations. Companies have also been looking at alternative production locations and alternative supply sources for the raw materials themselves[115]. EU Member States are also negotiating raw materials agreements bilaterally with third countries, for example Austria with Mongolia[116].

Textbox A-4 Vietnam-EU free trade agreement

The Free Trade Agreement negotiations between the EU and Vietnam were completed in 2015 and resulted in the elimination of nearly all tariffs, including with some critical raw materials such as tungsten, used in metal alloys like tungsten carbide, which is of relevance for the wind energy sector in particular[117].

Strengthening overall state governance and promoting a sound investment climate

The EU is dependent on many third countries for its supply of critical raw materials. Many of these countries are developing or middle-income countries, without the same level of policy effectiveness or rule of law as in the EU[118]. In the short- to medium-term, raw materials will continue to be imported to the EU from these third countries. As such, the RMI supports the need for state-strengthening initiatives to promote sustainable raw materials management practices in these third countries, whether through development cooperation, EU-level initiatives (Textbox A-5) or other collaborations.

Textbox A-5 Conflict-free minerals

In 2017, regulation to prevent the minerals trade from funding conflict and human rights violations was approved by MEPs. The extra due diligence requirements for EU companies will apply as from January 2021 in line with the OECD's Due Diligence Guidance. This regulation will ensure that tin, tantalum, tungsten and gold are exclusively imported from responsible sources[119]. However, the regulation only applies to EU companies using the 3TG minerals to manufacture their products. Research results from the EU's STRADE Project recommended the generation of raw materials import footprints, to allow improved understanding of the socio-economic and environmental footprint of the EU's materials imports[120].

[113] EC (2014). WTO confirms China's export restrictions on rare earths and other raw materials incompatible with WTO rules. http://trade.ec.europa.eu/doclib/press/index.cfm?id=1050
[114] Rabe, W. (2017). China's supply of critical raw materials: Risks for Europe's solar and wind industries? http://www.sciencedirect.com/science/article/pii/S0301421516304852
[115] Rabe, W. (2017). China's supply of critical raw materials: Risks for Europe's solar and wind industries? http://www.sciencedirect.com/science/article/pii/S0301421516304852
[116] BMDW (2018). The Austrian minerals strategy. https://www.en.bmdw.gv.at/Energy/AUSTRIANMINERALSSTRATEGY/Seiten/default.aspx
[117] EC (2016). EU-Vietnam Free Trade Agreement: Agreed text as of January 2016. http://trade.ec.europa.eu/doclib/press/index.cfm?id=1437
[118] ECDPM (2017). EU's ore and metal import flows and engagement towards responsible sourcing in industry supply chains. http://ecdpm.org/great-insights/mining-for-development/eus-ore-metal-import-flows-engagement-towards-responsible-sourcing-industry-supply-chains/
[119] EC (2018). Conflict minerals regulation. http://ec.europa.eu/trade/policy/in-focus/conflict-minerals-regulation/
[120] STRADE (2017).EU raw material import flows – acknowledging non-EU environmental and

In some cases, initiatives in third countries themselves have led to improved raw materials governance (Textbox A-6).

Textbox A-6 Responsible cobalt

Cobalt is one of the most essential minerals for the low-carbon energy system, with primary uses in (super-)alloys, batteries and magnets. The Democratic Republic of the Congo (DRC) is the largest supplier of cobalt worldwide (64% of global cobalt production) and has been internationally reprimanded for human rights abuses including child labour. Although Finland supplies 66% of the refined cobalt that the EU uses directly, it is not possible to exclude the presence in the EU of "dirty" cobalt from countries such as the DRC[121]. Nevertheless, recent developments in Congolese mining tax regulations increasing the tax burden for mining companies in DRC indicate increased protectionist approaches in third countries and perhaps the need to increase cobalt mining in the EU[122].

Furthermore, businesses in China (the main destination for Congolese cobalt) have joined forces in the "fight" against "dirty" cobalt through the Responsible Cobalt Initiative and mining companies themselves have recently proposed Blockchain technology for the monitoring of cobalt supply chains, aiming to eliminate human rights abuses through data transparency. Challenges include monitoring the informal mining sector, widespread in many third countries[123].

Challenges in cooperating to strengthen third countries include potential association with negative/harmful practices. For example, the Ambatovy nickel mine in Madagascar was originally supported by the European Investment Bank and has since been scrutinised by watchdogs who found that the mine generated substantial negative environmental and social impacts[124].

Pillar 2: Supply from European sources

The second pillar of the EU's RMI focuses on fostering domestic supply of required raw materials. Although this approach would seem optimal in terms of achieving several different EU objectives, such as secure supply of raw materials and economic development in the mining sector, in reality it presents several challenges. These refer to setting the right framework conditions for fostering sustainable EU supply, developing knowledge and skills and increasing public awareness.

Regulatory framework conditions for sustainable EU raw materials exploration and supply

Despite the large mineral potential of geological zones in Europe, particularly in Sweden and Greenland[125], mining of critical raw materials (and base metals[126]) is not dominant in Europe[127]. National mineral policies across the EU are not coherent, societal opposition to mining is strong, geological mapping efforts are abundant but uncoordinated and exploration

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social footprints. http://www.stradeproject.eu/fileadmin/user_upload/pdf/STRADEPolBrf_02-2017_RawMaterialFlows_Mar2017_FINAL.pdf

[121] See e.g. https://im-mining.com/2018/12/20/rajapalot-finland-significant-strategic-gold-cobalt-resource/

[122] BBC (2018). DR Congo signs new mining law despite companies' opposition. http://www.bbc.com/news/world-africa-43355678

[123] Reuters (2018). Blockchain to track Congo's cobalt from mine to mobile. https://www.reuters.com/article/us-mining-blockchain-cobalt/blockchain-to-track-congos-cobalt-from-mine-to-mobile-idUSKBN1FM0Y2

[124] EIB in Africa (2017). A tale of reverse development. https://www.eibinafrica.eu/tag/mining/

[125] Goodenough, K.M., et al. (2016). Europe's rare earth element resource potential: An overview of REE metallogenetic provinces and their geodynamic setting. https://ac.els-cdn.com/S0169136815300755/1-s2.0-S0169136815300755-main.pdf?_tid=f32a1d38-efd1-11e7-a4d7-00000aab0f27&acdnat=1514907246_2a14336fcad81b4ab6c2d9b54e5a2e63

[126] World Bank (2017). The Growing Role of Minerals and Metals for a Low Carbon Future. http://documents.worldbank.org/curated/en/207371500386458722/The-Growing-Role-of-Minerals-and-Metals-for-a-Low-Carbon-Future

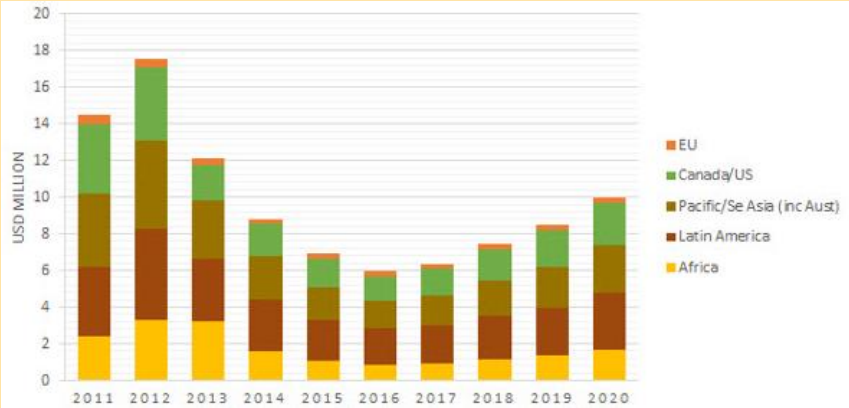
[127] EURARE Website (2017). Rare earth element deposits in Europe. http://www.eurare.eu/countries/home.html

budgets are insufficient (Textbox A-7). The RMI recommends the development or improvement of national mineral policies[128], as well as a strategic and centralised approach at the EU level to increase mining efforts[129].

Textbox A-7 EU mining exploration budgets

Exploration budgets globally have been decreasing since the commodity price collapse starting in 2014-2015 and remain substantially lower than exploration budgets in other parts of the world (Figure A-3). In 2015, EU-based mining and exploration companies allocated just 13% of exploration budgets to EU countries. Furthermore, exploration in the EU is also not expected to grow significantly. To improve mineral exploration in the EU, modification of mining regime structures and improved support to junior explorers could be helpful policy changes.

Figure A-3 Exploration expenditures by location between 2011-2020 (Source: SNL Metals & Mining Consulting).[130]



Stimulating public awareness and support for EU mining needs

The ease with which the general public has been seen to collectively oppose large projects in the EU presents a challenge for development in general, and mining projects specifically. In the EU, the public frequently and easily organises itself in protests to express opposition to new projects. Protests frequently take place with communities expressing resistance based on NIMBY-ism and land-use conflicts resulting from high population density and the abundance of protected areas[131]. This societal opposition can result in long lead times for mining projects (e.g. 10-15 years), as well as project cancellations (Textbox A-8). The general public's understanding of the technical information associated with new mining projects should never be taken for granted and since mining projects are inherently technical, it would be recommended to produce thorough information campaigns for all mining projects, to be delivered by engagement experts.

Textbox A-8 Cancellation of mining projects

In 2013, mining rights to Norra Kärr, a Rare Earth Elements (REE) deposit in Sweden, were granted to Canadian firm Tasman Metals. Proposed mining plans included the purchase of several local

[128] EC (2014). Report on National Minerals Policy Indicators Framework conditions for the sustainable supply of raw materials in the EU. http://ec.europa.eu/DocsRoom/documents/5562/attachments/1/translations/en/renditions/native
[129] ERT (2013). Raw materials in the industrial value chain: an overview. https://www.ert.eu/sites/ert/files/generated/files/document/raw_materials_in_the_industrial_value_chain_-_january_2013.pdf
[130] SNL Metals & Mining (2017). Worldwide mining exploration trends. https://marketintelligence.spglobal.com/our-thinking/ideas/report-worldwide-mining-exploration-trends-2017
[131] EC (2011). Guidance on undertaking new non-energy extractive activities in accordance with Natura 2000 requirements. http://ec.europa.eu/environment/nature/natura2000/management/docs/neei_n2000_guidance.pdf

houses, which (among other aspects) resulted in opposition from community members[132]. In 2016, the mining license was cancelled by the Supreme Administrative Court of Sweden on the grounds of insufficient supporting evidence from environmental studies[133].

Strict environmental regulations specifically also present a challenge for expanding mining activities in the EU. For example, in 2018 the Finnish nickel mine Ahtium Oyj filed for bankruptcy following a severe environmental damage case[134]. In order to support increasing mineral needs for the low-carbon energy system, changes in mining policy and increased budget expenditure on exploration must be achieved in the EU.

The difficulties faced with onshore mining options may provide sufficient reason to continue supporting alternative efforts, such as deep-sea mining (Textbox A-9).

Textbox A-9 New exploration opportunities: deep sea mining

Further assessment of possibilities to increase primary production of raw materials in the EU will also depend on consideration of new sources, such as **deep-sea mining**. Seabed mining research has received attention in recent years, since the EU seabed offers potentially vast quantities of raw materials, including rare earth elements found in the top layers of some deep-sea clays. The Commission has already supported substantial research on deep sea mining, although not necessarily in the context of the low-carbon energy transition[135]. High costs of implementing deep-sea mining and the continued gaps in knowledge, also to explore the deep seas in an environmentally sustainable way, result in relatively slow progress[136]. Nevertheless, it will be an area to watch since growth potential has been identified[137].

Knowledge, research and skills for sustainable supply from EU sources

In order to mitigate raw materials dependencies, it will be important to develop solutions within the EU. In order to achieve this, the development of EU-based knowledge and skills will be essential.

In 2017, the Critical Raw Materials (CRM) list was updated based on a refined methodology to identify raw materials with high supply-risk and high economic importance (Table A-1). The refined methodology remains comparable to previous CRM lists, while also catering more effectively to criticality, i.e. the current and past raw materials situation (a "snapshot in time"), rather than resilience (which relates to response systems). A recent publication by the EC's STRADE project suggests that EU work on Critical Raw Materials has indeed improved the level of knowledge of the EU's raw materials[138]. The CRM list also includes maps illustrating the EU's CRM dependencies, as well as supply trends (Figure A-4 and Figure A-5).

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132 Naturskyddsföreningens kansli Sydost (2015). [IN SWEDISH] Brytning av sällsynta jordartsmetaller i Norra Kärr? Fakta, utvärdering och synpunkter. https://sydost.naturskyddsforeningen.se/wp-content/uploads/sites/315/2015/08/PM-Norra-K%C3%A4rr.pdf

133 Tasman Metals (2016). Swedish Supreme Administrative Court Cancels Norra Karr Mining Lease. http://tasmanmetals.se/2016/02/swedish-supreme-administrative-court-cancels-norra-karr-mining-lease/

134 Reuters (2018). Finland's former Talvivaara files for bankruptcy. https://www.reuters.com/article/us-ahtium-bankruptcy/finlands-former-talvivaara-files-for-bankruptcy-idUSKCN1GI11Z

135 EC Website (2018). Seabed mining. https://ec.europa.eu/maritimeaffairs/policy/seabed_mining_en

136 EC (2018). Seabed mining. https://ec.europa.eu/maritimeaffairs/policy/seabed_mining_en

137 EC (2012). Blue growth: opportunities for marine and maritime growth. https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/docs/body/com_2012_494_en.pdf

138 STRADE (2017). Strategic Dialogue on Sustainable Raw Materials for Europe (STRADE): EU raw material import flows - acknowledging non-EU environmental and social footprints. http://www.stradeproject.eu/fileadmin/user_upload/pdf/STRADEPolBrf_02-2017_RawMaterialFlows_Mar2017_FINAL.pdf

Table A-1 CRM list 2017 (Source: EC[139]).

2017 CRMs (27)[140]			
Antimony	Fluorspar	LREEs (including neodymium)	Phosphorus
Baryte	Gallium	Magnesium	Scandium
Beryllium	Germanium	Natural graphite	Silicon metal
Bismuth	Hafnium	Natural rubber	Tantalum
Borate	Helium	Niobium	Tungsten
Cobalt	HREEs (including dysprosium	PGMs	Vanadium
Coking coal	Indium	Phosphate rock	

Figure A-4 Countries accounting for largest share of EU supply of CRMs

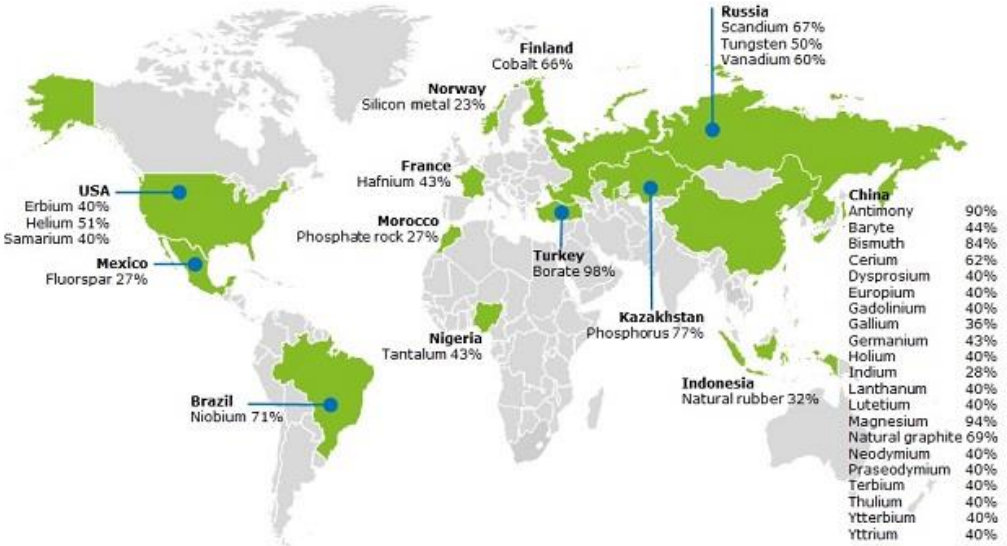
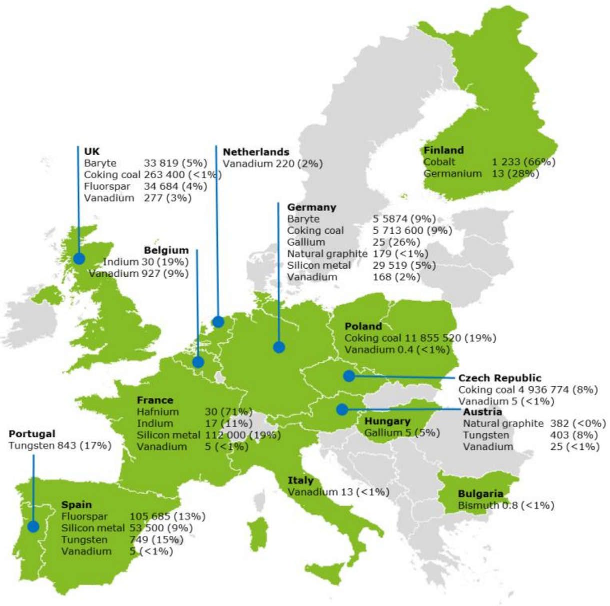


Figure A-5 EU average production of primary CRMs in tonnes (and share of supply to the EU), 2010-2014



[139] EC (2017). Critical raw materials list. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52017DC0490&from=EN
[140] HREEs=heavy rare earth elements, LREEs=light rare earth elements, PGMs=platinum group metals

Other initiatives promoting improved knowledge and skills in the field of raw materials include the European Union Raw Materials Knowledge Base (EURMKB)[141], the European Rare Earths Competency Network (ERECON)[142] and the European Institute for Innovation and Technology Knowledge and Innovation Community (EIT-KIC) on Raw materials[143]. These initiatives will play an essential part in ensuring the development of the correct raw materials skills base in the EU for the purposes of developing homegrown solutions.

Pillar 3: Resource efficiency, recycling and substitution

Resource efficiency is becoming increasingly important in the EU, particularly in the context of the circular economy and associated work, including the Circular Economy Strategy and the JRC's recently published background report on CRM and the Circular Economy[144]. Resource efficiency, recycling and substitution are important parts of this pillar.

Resource efficient products and product design

Resource efficiency, a core component of the RMI, has been promoted in recent years particularly in the context of the circular economy. It is an important consideration in most sectors and has recently been considered in the renewable energy sector (Textbox A-10). Resource efficiency refers to the optimum use of resources throughout product lifecycles but also in supply chains i.e. from source to sink. While also reducing costs for producers and importers, resource efficiency can reduce raw materials dependencies and associated security of supply risks. Life Cycle Assessments are an essential tool to assess opportunities for product improvement while also identifying opportunities for resource efficiency. The various forms of resource efficiency include:

- Manufacturing efficiency realised through quality control and waste minimisation, often correlating with advanced manufacturing technologies;
- Value chain optimisation through cooperation and coordination across different companies involved at different steps of the value chain, which can generate efficiency gains[145];
- Resource-efficient product design, determining materials required and recyclability at end-of-life. Optimal design can be achieved through the following main techniques:
    - Substitution of materials with more efficient ones;
    - Reducing the amount of materials used; and,
    - Closing the lifecycle loop through consideration of materials compatibility with available recycling infrastructure and recovery practices.

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[141] EC (2018). European Union Raw Materials Knowledge Base (EURMKB). https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/knowledge-base_en

[142] EC (2018). European Rare Earths Competency Network (ERECON). https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/erecon_en

[143] EIT Raw Materials. (2018) Raw Materials Academy. https://eitrawmaterials.eu/eit-rm-academy/

[144] JRC (2017). CRM and the circular economy. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC108710/jrc108710-pdf-21-12-2017_final.pdf

[145] This value chain optimization often occurs under the term 'industrial symbiosis'. See e.g. https://ec.europa.eu/environment/ecoap/about-eco-innovation/experts-interviews/20140127_industrial-symbiosis-realising-the-circular-economy_en

Textbox A-10 Improving materials efficiency for wind and solar

There are several efforts ongoing in the low-carbon energy sector relating to the achievement of improved materials efficiency, which reduces raw material needs. These include:

- Ongoing technological innovation in the wind energy sector aimed at increasing the reliability of geared designs and driving down the cost of direct-drive designs, which would in turn help to reduce rare earth element content[146].
- Concentrated solar power (CSP), which has been considered as an area for improved materials efficiency due to high production costs and opportunities for 'thinning,' for example through decreasing the silver content in panels[147].
- Innovative technologies for achieving high materials efficiency for solar cells, including 'metal wrap through technology' or 'buried contact'[148].

Recycling and secondary raw materials

Recycling represents an important way to deal with scarcity of supply issues concerning certain critical raw materials, while also achieving environmental benefits such as reduced water and energy use compared to mining. However, despite the abundance of innovative projects focusing on recycling, there are several limiting factors. In order to ensure long-term success of this mitigation measure, it will be important to remove the barriers to recycling that exist today[149].

Several CRMs display a high potential recycling rate. However, the recycling input of CRMs is generally low. One reason for this is that in several cases CRM recycling is not yet competitive and many CRMs are locked in long-life assets. This makes the construction of recycling plants, often needing specific and/or expensive technologies, economically unattractive in the short-term. Challenges to recycling also include collection, sorting and preparation (e.g. dismantling equipment), as well as limitations in recycling technology and recycling plant availability - Textbox A-11 illustrates challenges facing waste recycling in the EU. Given its challenges, it remains unclear to what extent successful recycling will be able to adequately meet the increasing raw materials demands, for example of the growing renewables sector[150]. Nevertheless, there are several examples of EU-funded projects supporting innovative recycling and recovery of raw materials, including enhanced recovery from landfill.

Textbox A-11 China curbs imported waste [151].

In March 2018, China's plans to implement restrictions on the import of solid waste entered into force with the aim of reducing the country's pollution burden. The full implications of this import curb for the EU have yet to be seen in practice. However, it is expected that EU's existing recycling facilities will face substantial pressure, placing additional pressure on the EU's strategic commitments such as the Circular Economy Strategy. Although this ban concerns conventional waste (e.g. paper and plastic), it nevertheless highlights the need for the EU to critically consider how and where it would recycle raw materials waste.

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[146] World Bank (2017). The Growing Role of Minerals and Metals for a Low Carbon Future. http://documents.worldbank.org/curated/en/207371500386458722/The-Growing-Role-of-Minerals-and-Metals-for-a-Low-Carbon-Future

[147] Grandell, L. (2016). Role of critical metals in the future markets of clean energy technologies. http://www.sciencedirect.com/science/article/pii/S0960148116302816

[148] Saga, T. (2015). Advances in crystalline silicon solar cell technology for industrial mass production. https://www.nature.com/articles/am201082.pdf

[149] EC (2015). Closing the loop - an EU action plan for the Circular Economy. http://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF

[150] JRC (2017). CRM and the circular economy. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC108710/jrc108710-pdf-21-12-2017_final.pdf

[151] BIR (2017). China will import only the highest quality waste and scrap: thresholds for contaminants notified to the WTO. http://www.bir.org/assets/PressCuttings/611Chinese-Thresholds.pdf

Substitution

Substitution of critical raw materials with less critical ones available or developed in the EU presents an effective way to reduce raw materials dependence. However, in the short- to medium- term, industry is unlikely to act independently to develop substitution techniques, since raw materials are expected to remain abundant during this period and there are industry concerns around technology-specific performance requirements[152]. Ongoing policy intervention in this area will therefore be required to create the right incentives for substitution technologies. For example, through targeted materials innovation programmes under Horizon 2020 such as the CRM-InnoNet project. In all cases, substitution efforts should be aligned with technology-specific performance requirements, as well as being effectively scalable.

Textbox A-12 Substitution of critical raw materials in low-carbon technologies[153]

A 2016 study highlighted the importance of policy-driven substitution initiatives given that industry currently does not face all the required incentives. The study also underlined the need to develop permanent magnets without rare earth elements for the wind energy sector, as well as mainstreaming organic light-emitting diodes (OLEDs) in the lighting sector and considering the diffusion of hybrid technology in electric vehicles (which in comparison to batteries, does not have a substitute). Overall, the study also concludes on the importance of a combined approach to mitigating raw materials dependencies in low-carbon technologies.

A.3 European fossil energy security of supply policies

Next to raw materials policies, a second main area of policies where lessons can be learned for future energy technology dependence are the existing European energy security of supply policies. These focus predominantly on fossil fuels.

Although the renewables sector has been growing steadily in the last decade, Europe's energy system is still predominantly fossil fuel dependent, with 83% of the primary energy supply originating from fossil sources (Figure A-6). Furthermore, these fossil fuels are mainly imported, generating high fossil fuel dependency in Europe – particularly with respect to oil (Figure A-7).

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[152] CRM Alliance (2018). Research and development: European innovation partnership. http://criticalrawmaterials.org/policy/research-development/

[153] JRC (2016). Substitution of critical raw materials in low-carbon technologies. https://setis.ec.europa.eu/sites/default/files/reports/crm_substitution_online_report.pdf

Figure A-6 Primary energy supply in EU is still strongly based on fossil fuels. (Source: Trinomics, 2017)[154].

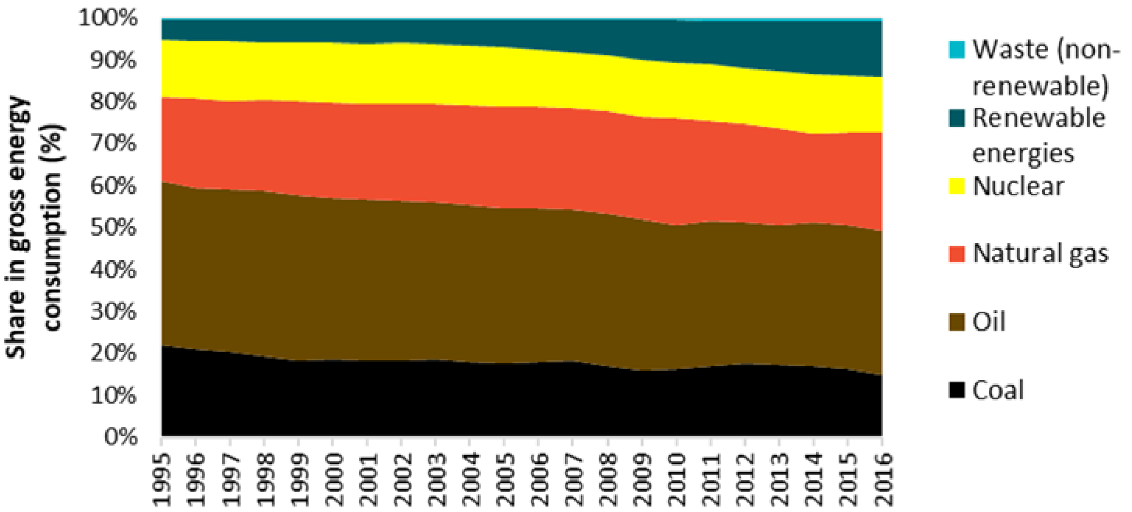
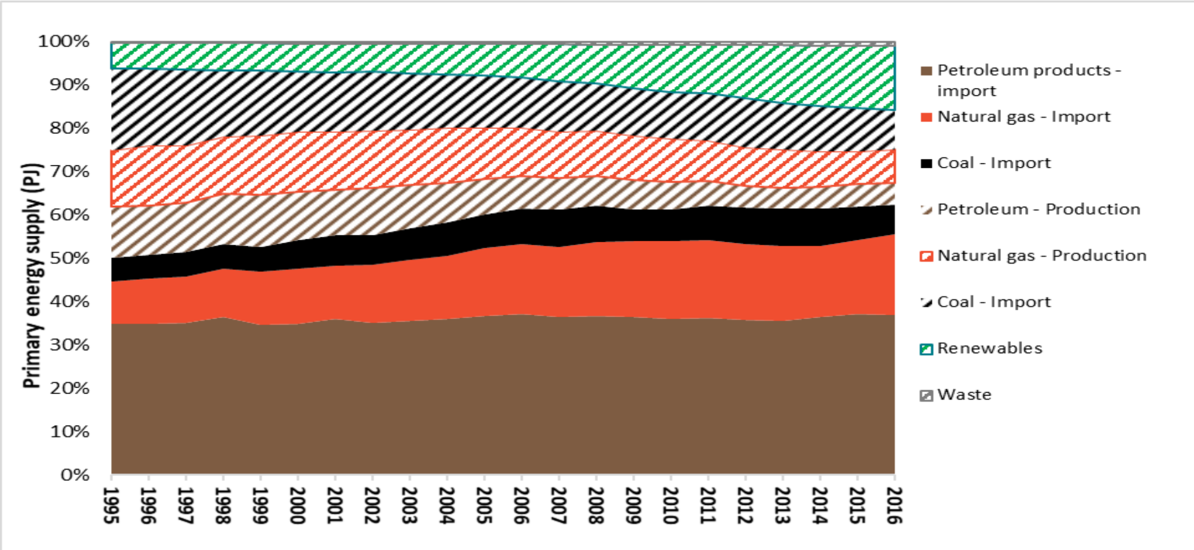


Figure A-7 Share of imports in the EU's primary energy supply is still increasing. (Source: Trinomics, 2017)[155].



In the 2016 EU Reference Scenario, oil, gas and coal are still projected to have a share of respectively 33%; 25% and 6% in the European energy system in 2050. Furthermore, EU's fossil import dependency shows a slowly increasing trend in the coming decades, from 53% in 2010 to 58% in 2050[156]. Any policies directed at mitigating dependencies on new low-carbon energy technologies therefore will have to be combined with existing fossil energy security of supply policies. In addition, some general mechanisms applied by these existing policies might also be relevant for low-carbon energy technology dependency policies. These are explored in the following subsections on oil and gas security of supply policies.

[154] Own figure based on the addition of the net energy imports and primary energy supply from Eurostat (2017) Complete energy balances - annual data (nrg_110a).
[155] Own figure based on the addition of the net energy imports and primary energy supply from Eurostat (2017) Complete energy balances - annual data (nrg_110a).
[156] EC (2016) EU Reference Scenario 2016, https://ec.europa.eu/energy/en/data-analysis/energy-modelling

Oil

EU energy security of supply policies started in the 1970s after the first oil crisis. Since then, emergency oil stocks and diversification of countries of origin of petroleum have been integral elements of security of supply policy making. According to the 2009 EU Oil stocks directive[157], EU and Member States have to take several measures to ensure a stable reserve of emergency oil stocks within the EU that can be used in case of sudden supply disruptions:

- EU countries must maintain emergency stocks of crude oil and/or petroleum products equal to at least 90 days of net imports or 61 days of consumption, whichever is higher;
- Stocks must be readily available so that in the event of a crisis they can be allocated quickly to where they are most needed;
- EU countries must send the European Commission a statistical summary of their stocks at the end of each month. This summary must state the number of days of net imports or consumption that the stocks represent;
- During a supply crisis, the Commission is responsible for organising a consultation between EU countries. Withdrawals from stocks should not be made before this consultation, except in a very urgent situation;
- An Oil Coordination Group serves as a standing advisory group that facilitates coordination between EU countries and the Commission.

Gas

The most recent and overarching energy security of supply strategy is the 2014 Energy Security Strategy[158]. It is directed primarily at gas security of supply and aims to ensure a stable and abundant supply of energy for European citizens and the economy through both short- and long-term measures.

On the short term, in 2014 38 European countries, including all EU countries, carried out energy security stress tests. They simulated two energy supply disruption scenarios for a period of one or six months: A complete halt of Russian gas imports to the EU and a disruption of Russian gas imports through the Ukrainian transit route. The tests showed that a prolonged supply disruption would have a substantial impact on the EU. Eastern EU countries and Energy Community countries would be particularly affected. The report also confirmed that if all countries cooperate with each other, consumers would remain supplied even in the event of a six-month gas disruption.

Based on the analysis of the stress tests, several short-term measures were carried out in preparation for the winter of 2014-2015. Furthermore, the EU's Gas Coordination Group monitors developments in the gas supply throughout the year. The Commission also asked EU and Energy Community countries to prepare regional energy security preparedness plans, which were reviewed and adopted in 2015[159].

For the longer term, main objectives of the EU energy security of supply strategy are:

- Increasing energy efficiency (through the 2012 Energy Efficiency Directive);

[157] EC (2009) 2009/119/EC
[158] EC (2014). European Energy Security Strategy. http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52014DC0330&qid=1407855611566
[159] See https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/energy-security-strategy

- Increasing energy production in the EU and diversifying supplier countries and routes;
- Internal market development and infrastructure interconnections to improve responsiveness to supply disruptions (through the 2017 Security of Gas Supply Regulation and ENTSOG);
- Speaking with one voice, regarding agreements with non-EU countries (the Energy Union); and,
- Strengthening emergency mechanisms, including emergency oil stocks (through the EU's Oil Stocks Directive).

Textbox A-13 Gas security of supply and Russia

The 2014 EU energy security of supply strategy found its political origins in two major gas supply disruptions in 2006 and 2009 as a result of a conflict between the Ukraine and Russia. Russia still is one of the EU's main suppliers of fossil fuels, particularly natural gas. As a result, Russia and Russian fossil fuels are the subject of several agreements and discussion forums in place to protect EU interests. The EU-Russia energy dialogue is the main forum under which these discussions take place. Discussions centre around energy forecasts and strategies, market development and energy efficiency. There also figures a specific gas advisory council under the dialogue mechanism[160].

A.4 Mitigation measures in other relevant sectors

In this section we will discuss the status and mitigation measures that are available and/or have been developed in other sectors. Although several sectors display raw materials and component-related dependencies, two particularly relevant sectors for discussion include defence/ aerospace and ICT. In both areas security of supply risks play an important role, therefore possible lessons for low-carbon energy technology dependencies could be learned.

Defence and aerospace

Like the low-carbon energy technology sector, the EU aerospace & defence sector displays significant raw materials dependencies. These exist for instance in the production of precision military equipment, as well as component-related dependencies, e.g. for military vehicles. Although there are mitigation measures in place for raw materials dependencies, mitigation measures for component-related dependencies are less clear and merit further attention.

One of the most prominent mitigation measures for raw materials dependencies currently in place in the defence sector is evident in the United States. Assessments of increasing raw materials dependency by the US Defence Agency contributed to the development of the current US National Defence Stockpile programme operated by the Defence Logistics Agency (Strategic Materials)[161]. Although not directly comparable to the EU given differing industrial structures and import dependencies, this serves to highlight the importance of raw materials dependencies in the defence industry.

According to a 2016 JRC assessment, the EU defence sector displays a high level of dependency on imported components in semi-finished stages including alloys, compounds

[160] See https://ec.europa.eu/energy/en/topics/international-cooperation/russia
[161] Defence Logistics Agency (2018). Strategic materials. http://www.dla.mil/HQ/Acquisition/StrategicMaterials.aspx

and composite materials with special properties and high-performance requirements that are not easily substituted[162]. The defence industry's aeronautics and electronics sectors are especially dependent on these semi-finished imports. A 2016 JRC assessment concluded that 47 processed and semi-finished materials are essential to the defence sector, requiring 16 raw materials from the EU's CRM list.

Also in the aerospace sector, critical dependencies on raw materials exist. The sector has a large demand for high-performing metal alloys, which take on higher values due to the precise engineering required. In the defence industry, the main alloys used for aircraft applications demonstrate specific characteristics with respect to heat, corrosion and expansion. The most important aerospace material in the EU is aluminium alloy (46% market share)[163]. Furthermore, it is estimated that France will demonstrate the greatest growth in demand in the aerospace sector, which marks interregional differences in the EU. Although recycling has been considered for raw materials and components in the aviation sector, developments are still in their infancy (**Textbox A-14**).

Although the EU is an important manufacturer of certain alloys, there is a lack of major manufacturers of aerospace-grade carbon fibres and their precursors e.g. polyacrylonitrile. Demand for these specialty composite materials is expected to increase in relevance for the defence sector, potentially worsening import dependencies. The JRC recommendations for the sector to mitigate dependencies therefore focus on the need for the EU to improve its production capacities for specialty composite materials[164]. In addition, the JRC report on the EU defence sector recommends further civil-military RD&I synergies, as well as the inclusion of specialised component materials as part of the CRM assessment methodology. In other parts of the world, the composite materials challenge for aircraft has been approached through potential solutions offered by 3D printing of components, which could merit exploration also within the EU[165].

Textbox A-14 Substitution and recycling in the aerospace sector

In the aerospace sector, recycling of materials from aircraft was not a major consideration until recent years. Although little information is available (particularly for defence aircraft), it has now become common practice in the sector to account for all metals used and to aim to operate in a circular way. However, although there have been initiatives in the past concerning efficient treatment of end-of-life aircraft (e.g. the PAMELA project[166], originally funded by LIFE), currently there is no industry-wide best practice or EU directive. Aluminium, magnesium, titanium as well as steel are several materials currently recycled both from waste generated during the production of aircraft structure and engine components and from reclaimed components from end-of-life aircraft. Substitution is another option presently investigated in the aerospace sector. Carbon fibre composite materials are becoming more popular in the aeronautic applications, such as jet fighters, and large industrial players (e.g. Airbus and Boeing) have already initiated programmes for recycling carbon-fibre material.

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[162] JRC (2016). Raw materials in the European defence industry. https://setis.ec.europa.eu/sites/default/files/reports/raw_materials_in_the_european_defence_industry.pdf
[163] JRC (2016). Raw materials in the European defence industry. https://setis.ec.europa.eu/sites/default/files/reports/raw_materials_in_the_european_defence_industry.pdf
[164] JRC (2016). Raw materials in the European defence industry. https://setis.ec.europa.eu/sites/default/files/reports/raw_materials_in_the_european_defence_industry.pdf
[165] http://www.forbesindia.com/article/special/uaes-strata-partners-with-anil-ambanis-reliance-defence-ltd/45959/1
[166] EC (2011). End-of-life aircraft recycling offers high-grade materials. https://ec.europa.eu/environment/ecoap/about-eco-innovation/good-practices/eu/719_en

ICT

Like defence and aerospace, the EU ICT sector displays significant raw materials dependencies but also dependencies on imported products. In addition, it displays high infrastructure and network-dependencies that might be relevant for the low-carbon energy technology sector. The continued market growth in the ICT sector, which includes diverse applications from smart phones to medical equipment, increases pressure on raw materials supplies in this sector, including materials featured on the 2017 CRM list. However, most ICT equipment (e.g. laptops, mobile phones and circuit boards) is produced in Asia, resulting in additional EU product dependencies. **Textbox A-15** shows how the EU is trying to mitigate product import dependencies through recycling/refurbishment.

Textbox A-15 Refurbishment and reuse of ICT equipment

A study by the REBus[167] project, which itself is funded by Life+ and aims to implement resource efficient business models, suggested several ways of improving resource efficiency largely though increasing the longevity of existing ICT equipment while also providing cost savings. These include:

- Improved selectivity regarding which pieces of electronic equipment need to be replaced, particularly at the level of the user-interface such as reusable ICT equipment for business (e.g. keyboards, monitors and mice)[168];
- Leasing equipment;
- Using refurbished/ repaired ICT equipment;
- Incentives to keep equipment for longer; and,
- Increased proportion of secondary raw materials used in the production of ICT equipment.

The Dutch government suggested that the level of potential reuse of currently disposed ICT equipment is around 25%. Also, in the Netherlands, the Recover-E initiative applies circular economy rationale and sharing of best practices to ensure that ICT equipment remains useable for as long as possible[169].

Measures to mitigate infrastructure risks related to cyber-attacks are also relevant for the energy sector. Several dedicated publications on risks of cyber-attacks to smart grid development have been published in recent years[170]. Also, in 2017 an overall EU cyber security package was adopted[171]. The package contains the following main measures:

- expanding the mandate of the EU cybersecurity agency ENISA;
- promoting one cybersecurity market within the EU, including the establishment of a certification framework;
- a directive on security of network and information systems;
- a blueprint for a rapid emergency response;
- strengthening binding international law around cyber security, that the United Nations (UN) Charter, applies in cyberspace, promotion of voluntary norms and regional confidence building measures as well as bilateral security dialogues.

The ICT measures seem to be directed to crisis response in case of an acute incident, but also at prevention of the emergence of such a crisis. They contain some governance measures (a dedicated agency) as well as strengthening of multilateral as well as bilateral diplomacy in this field.

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167 REBUS (2017). http://www.rebus.eu.com/

168 Rijkswaterstaat (2017). REBus ICT Sector report. https://www.pianoo.nl/sites/default/files/documents/documents/rebussectorreportictlessonsoktober2017.pdf

169 Recover-E (2018). http://recover-e.nl/

170 E.g. Ivan L.G.Pearson ( ) Cyber security in Europe, Energy Policy39(2011)5211–5218; Wenye Wang & Zhuo Lu (2013) Cyber security in the Smart Grid: Survey and challenges, Computer Networks, Volume 57, Issue 5, 7 April 2013, Pages 1344-1371

171 https://ec.europa.eu/digital-single-market/en/cyber-security

Annex B - Mitigating dependencies according to academic literature

B.1 Introduction

We reviewed several key academic papers and reports on the subject of energy technology dependencies. Several measures for mitigating dependencies are already discussed extensively in the literature. Such mitigation measures found in the literature focus on (a) developing the EU's technology leadership and (b) ensuring security of supply.

B.2 Industrial competitiveness

Several of the mitigation measures discussed in the literature also have implications for industrial competitiveness, including: recycling, substitution and the development of know-how and specialised skills. Mostly, measures associated with industrial competitiveness have to do with developments in **RD&I** and associated co-benefits for industrial competitiveness.

According to a 2016 study by Blagoeva et al. at the JRC[172], **recycling** is a viable solution for several rare earth minerals. However, recycling rates are often not favourable due to long-term equipment duration. Regarding wind, neodymium and dysprosium are complex to reclaim and recycling from small devices such as mobile phones only yields small quantities, which are insufficient for wind turbines. Further research is required to overcome barriers in the recycling sector, for example the capital intensity of setting up recycling facilities and the requirement to "design-for-recycling" to facilitate the dismantling process. This research is essential in order to achieve potential co-benefits such as employment, economic growth, partnerships and competitive advantage.

The same study also discusses **substitution**. The JRC uses a specific definition of substitution and substitutability, illustrated further in its 2017 assessment of the methodology for establishing the EU list of Critical Raw Materials[173]. Substitution of component materials in wind turbines is possible but also of full component parts. For example, a company called Nordex has substituted permanent magnets in wind turbines with other technologies. However, according to work by Rabe et al (2017), replacements for permanent magnets tend to work less well, which could hinder global competitiveness, making the region more dependent on China in the long term[174]. Another JRC study by Pavel et al. (2016) focused exclusively on substitution[175], highlighting risks in placing substitute battery components on the market due to the electric vehicle models that currently dominate the market. Although substitution could indeed result in similar co-benefits as with recycling, competitive advantage should be underlined since the development of substitutes primarily concerns research and innovation. Policy developments should focus on closing this gap in deploying new (alternative) technologies to the market.

172 https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/assessment-potential-bottlenecks-along-materials-supply-chain-future-deployment-low-carbon

173 https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/assessment-methodology-establishing-eu-list-critical-raw-materials-annexes

174 http://www.sciencedirect.com/science/article/pii/S0301421516304852

175 https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/substitution-critical-raw-materials-low-carbon-technologies-lighting-wind-turbines-and

Some of the literature suggested that a key focus area to achieve the leapfrogging of new technologies in the sector (and the achievement thereby of industrial competitiveness) should be the development of **know-how**. Solar and wind energy sources come with substantially different transportation, installation, maintenance and safety requirements as compared to traditional fossil fuel energy sources. **Specialised skills** will be required and literature such as the IEA's RE-SUPPLY report (2012) argues that there are specific roles for both industry and the EU in supporting training and skills transfer (particularly for wind)[176]. Some EU-driven frameworks for such training are already in place, for example the Raw Materials University Days[177], illustrating a potential springboard to focus on the energy technology dependence mitigation needs of the low-carbon energy technology sector. Indeed, such know-how has been identified as a priority area by the European Innovation Partnership on Raw Materials[178]. Research with other countries also presents an opportunity to develop know how, although it may not necessarily result in industrial competitiveness since innovative ideas would then be shared. Nevertheless, existing research on topics such as substitution and recycling research shows that substantial financing is already in place in the EU to develop EU-based competitive advantage in this area[179].

B.3 Security of supply

Several of the mitigation measures discussed in the literature also have implications for security of supply, including: raw materials exploration and extraction, innovation-based materials efficiency and raw materials diplomacy and trade. Measures associated with security of supply concern **supply-side** developments.

Regarding theories around security of supply mitigations, much of the literature focused on **raw materials**. Increased exploration and extraction of relevant rare earth elements in the EU and in new locations worldwide has been the subject of much academic deliberation. In 2017, a World Bank study highlighted the importance of improved raw materials mapping in developing countries[180]. Although mineral mapping efforts have taken place in the EU[181,182], the extent to which these mapping exercises have been used to establish new suppliers requires further work. On a global scale, the best efforts at mapping international resources are limited to the United States Geological Survey (USGS) indicating that the EU should give serious consideration to partnerships. Nevertheless, a 2018 interview conducted with Claudiu Pavel of the JRC suggested that in fact the EC's Raw Materials Information System was cutting-edge, promising to consolidate all relevant raw materials in one comprehensive website[183]. Indeed, know-how has been identified as a priority area by the European Innovation Partnership on Raw Materials[184]. Certainly, knowledge of new raw materials resources (and the eventual extraction thereof) presents an opportunity for improved **crisis**

[176] http://iea-retd.org/archives/publications/re-supply
[177] https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/raw-materials-university-day-%E2%80%93-zagreb-croatia-%E2%80%93-14-june-2018
[178] https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/looking-towards-future-strategic-orientations-eip
[179] For example, several EU-funded projects have taken place in the field of rare earth substitution in permanent magnets in recent years including projects such as ROMEO, NANOPYME, REFREEPERMAG, MAG-DRIVE, Suprapower project, INNWIND.EU and EcoSwing Horizon 2020.
[180] http://documents.worldbank.org/curated/en/207371500386458722/The-Growing-Role-of-Minerals-and-Metals-for-a-Low-Carbon-Future
[181] https://esdac.jrc.ec.europa.eu/content/map-indicating-availability-raw-material-soils-european-union-organic-soil-material-b-soil
[182] http://www.eurare.eu/countries/reemap.html
[183] http://rmis.jrc.ec.europa.eu/
[184] https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/looking-towards-future-strategic-orientations-eip

management in the EU. Nevertheless, as mentioned by the final ERECON report[185] (2014), the issue of **barriers to entry** to new mines remains irrespective of the knowledge and the know-how that is developed.

In some of the studies that we reviewed, **innovation-based materials efficiency** is also highlighted as a mitigation measure. Generally, we would consider this to fit under the framework of **security of supply**, specifically on the **preventive** side. This measure involves the re-design of existing components and equipment to reduce or minimise material needs. Experts have for example concluded that dysprosium in permanent magnets can be reduced to insignificant amounts and companies have already begun to develop such efficiency measures. For example, Vestas has re-designed direct drive generators to use only 1/10 less of neodymium and dysprosium, which would reduce critical dependencies on China.

The EU has already made a substantial policy effort to recognise the risks involves with resource dependency, adopting the Raw Materials Initiative in 2008. **Raw materials diplomacy and related trade discussions** are holistic components of the EU's Raw Materials Initiative. The EC maintains several regular policy dialogues and study groups with international raw materials suppliers – e.g. EU-China Working Group on Raw Materials, as well as specific Commodity Study Groups. The EU also engages directly with China to avoid export duties. Specific pathways for this are through the EU-China Summit and the EU-China High Level Economic and Trade Dialogue. Mitigation measures associated with diplomacy and trade fall under preventive policies, although may also be used for crisis management as happened following the solar-related trade dispute between the EU and China in 2013[186]. The following box illustrates some diplomacy/trade measures already taken by the wind and solar sectors.

Wind

The wind sector is more concerned than the solar sector about critical raw materials bottlenecks. A short-term mitigation measure would be the development of joint ventures with Chinese counterparts. European companies have also signed long-term (multi-year) contracts with Chinese suppliers that involve trade in the final product rather than the component materials (which protects in the short term against potential quotas on the raw materials)[187].

Solar

Many suppliers have built a local presence in China, as well as continuing to apply pressure on the EU to improve protection against cheap Chinese products. Companies have also been looking at alternative production locations, as well as alternative supply sources for the raw materials [188].

B.4 Conclusions

Regarding industrial competitiveness, the literature is focused on the development of alternatives through additional research regarding recycling and design-for-recycling, substitution and know-how. In practice, the EU already has in place substantial frameworks for developing the region's industrial competitiveness, for example financing mechanisms

185 https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/erecon_en
186 http://www.eias.org/wp-content/uploads/2016/02/EU-Asia-at-a-glance-EU-China-Solar-Panels-Dispute-Yu-Chen.pdf
187 http://www.sciencedirect.com/science/article/pii/S0301421516304852
188 http://www.sciencedirect.com/science/article/pii/S0301421516304852

stimulating innovation. On the topic of security of supply, the focus is on alternative designs, trade relationships that are largely already in place via the Raw Materials Initiative and WTO trade agreements, as well as know-how focusing on the development of mining knowledge. The key area of overlap is know-how and associated RD&I, which clearly is already happening though perhaps not to the extent needed for some dependency areas.

Specific policy focus should be on stimulating the right kind of innovation, in clear alignment with other EU strategic priorities (such as the Circular Economy Strategy), as well as the removal of barriers currently in place (for example, the high capital costs of establishing rare earth metal recycling centres).

Annex C - Detailed recommendations for wind, solar PV and battery energy storage

C.1 Wind

Dependencies 1 & 2: neodymium & dysprosium

Technology leadership and preventive policies

- Expand EU RD&I for neodymium and dysprosium substitutes, most urgently for neodymium and possibly in cooperation with Japan and the US. This could be done in particular under the SET implementation plan wind offshore action 'materials science', next to general research stimulation options under Horizon2020 and Horizon Europe;
- Examine economically viable opportunities for small-quantity recycling, as in the case of neodymium and dysprosium. This could be done in particular under the SET implementation plan wind offshore action 'industrialisation';
- Install separate expert groups on neodymium and dysprosium under the Raw Materials Initiative;
- General extension of lifetimes of wind turbines by dedicated RD&I in order to increase materials efficiency and reduce dependency risks.

Prevention only

- Further examine mining options for neodymium and dysprosium within the EU under the second pillar of the Raw Materials Initiative, in particular investigating environmentally and economically viable possibilities for mining on demand at peak times only;
- Intensify multilateral and bilateral trade policy efforts to reduce the market power of China as a near monopoly supplier. Include neodymium and dysprosium dependency as an issue in future implementation plans of the EU-China energy dialogue;
- Intensify trade relations with neodymium/dysprosium suppliers other than China, in particular with Australia. This could be done under the recently started negotiations for an EU-Australia trade agreement.

Crisis management and containment

- Consider stockpiling of neodymium and dysprosium as an ultimate option to reduce current dependencies.

Dependency 3: Insulation materials for high voltage cables

Technology leadership and preventive policies

- Stimulate the continued development of possible substitutes for XLPE such as EPR and P-laser. This could take place under Horizon2020 and Horizon Europe programmes, as well as more specifically under the Wind Offshore SET implementation plan, actions 'system integration' and 'materials science'.

Prevention only

- None recommended.

Crisis management and containment

- None recommended.

Dependency 4: Fibreglass for wind turbine blades

Technology leadership and preventive policies

- Increase stimulation of development of RD&I that can provide an alternative to fibreglass, in particular carbon, through a reinforcement of activities foreseen in SET plan and through general RD&I stimulation under Horizon2020 and Horizon Europe.

Prevention only

- None recommended.

Crisis management and containment

- None recommended.

Dependency 5: Insulated Gate Bipolar Transistors (IGBTs)

Technology leadership and preventive policies

- None recommended, although the development of alternatives to IGBTs could be a direction for RD&I in the future.

Prevention only

- None recommended.

Crisis management and containment

- None recommended.

C.2 Solar PV

Dependencies 1 and 2: PV Cells and modules

Technology leadership and preventive policies

- Focus on tailored PV products in which design and aesthetics plays an important role next to price considerations in support for the EU PV cells and modules industry;
- Stimulate European RD&I on improved materials efficiency in solar cell and module technology, including perovskite and HIT options, in lower TRL levels and on building-integrated PV in the higher TRL levels;
- Build coalitions between EU PV, buildings and electronics industry around building-integrated PV;
- Foster PV recycling and design-for-recycle based on ongoing JRC research and through support for industry initiatives like PV-CYCLE and continuously stricter standard setting via the EU Eco-design and Energy Labelling Directives.

Prevention only

- As existing EU import measures against Chinese panels have been recently lifted, new measures of this kind are not likely to be supportive for reducing EU PV dependencies in the near future. However, a close monitoring of solar cell and module market concentration remains necessary, given the high dominance of Chinese producers in this market.

Dependency 3: Inverters

Technology leadership and preventive policies

- Stimulate demand for differentiated products, including high-quality EU inverters, through standard setting in the EU labelling directive;

Prevention only

- No measures recommended.

C.3 Battery Energy Storage Technology

Dependency 1: Cobalt

Technology leadership and preventive policies

- Further build on the initiatives to support battery manufacturing, fast charge, second use and recycling already envisaged under the SET battery implementation plan and the European Battery Alliance initiative in order to create an 'Airbus-like' joint industry effort towards an EU based battery industry;
- Step up EU funding for the development of alternatives to the current use of cobalt in batteries;
- Stimulate EU incentives for and investment in battery recycling industry to avoid future dependency on other regions for battery recycling, thereby possibly considering deposit refund approaches or extended producer responsibility schemes;
- Ensure specific coverage of recycling of cobalt from Li-ion batteries in the ongoing evaluation of the Batteries Directive;

Prevention only

- Investigate economic, socially and environmentally sustainable approaches to expanding mineral sources exploration in other countries, thereby using for cobalt similar import requirements as for the minerals in the EU's Conflict Minerals Regulation or in the OECD Due Diligence Guidance;
- Improve the collaboration between the EU and other regions (e.g. the US) on sharing knowledge regarding mapping raw materials reserves;

Crisis management and containment

- Consider stockpiling of cobalt as an ultimate option to reduce current dependencies;

Dependency 2: Cells

Technology leadership and preventive policies

- Sufficient access to finance for new parties entering the market in production and recycling should be assured in support of already foreseen actions to boost the EU battery cell industry;
- Attention needs to be paid to intellectual property rights for battery innovations from EU battery RD&I in order to allow for successful business models of innovative battery start-ups;
- Standardisation of EU cell production and recycling practices should be considered as a precondition for developing economies of scale for a growing EU battery industry;

Prevention only

None recommended.

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 is the report on mitigation strategies and policy recommendations.

Studies and reports

Publications Office
of the European Union