European Commission

# Study on energy technology dependence

Independent Expert Report

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Research and Innovation

**Study on energy technology dependence**

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# Study on energy technology dependence

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# Executive Summary

The overarching objective of this study is 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. As such, the study has a clear link with the Energy Union dimensions 'Security, solidarity and trust' and 'Research, innovation and competitiveness' and aims to provide relevant inputs to ongoing policy developments under the Energy Union strategy.[1]

The project is being carried out in six tasks:

1. Definition of the issues;
2. Development of a methodology;
3. Broad brush analysis of dependencies;
4. Selection of critical technologies and detailed assessment of the dependencies;
5. Mitigation strategy;
6. Recommendations and conclusions.

This report sets out the progress made in Tasks 1 and 2.
We have carried out the literature survey which has been used to identify the most appropriate methodology for this study. There is no single perfect method for assessing technology dependency. We noted that:

- Studies with relatively long-term time horizons tend to identify metrics which attempt to identify the conditions under which threats to supply may occur rather than specific causes of disruption;
- Studies with short time horizons can be specific in their assessments and can directly identify actions in relation to individual component dependencies.
- Most studies make use of the informed judgement of experts.

Our approach builds upon dependency and material security studies in the fields of defence, space and critical infrastructure and also the *Critical raw materials for the EU* study which investigated European dependency on rare earth elements, published in 2014 by the European Commission. This is the first time a method for assessing energy technology dependence has been developed. It identifies the conditions for potential elements (i.e. components, services, materials etc.) dependency and measures how critical the threat is. It helps prioritise responses and targets efforts to increase the resilience of critical elements. Chapter 1 (and associated appendices) discusses this in more detail. We have also provided a glossary of definitions and an English version of the didactical materials.

The methodologies are described in Chapter 2 (and associated Annexes). The method identifies the conditions for potential component dependency and then measures how critical

[1] The Communication Accelerating Clean Energy Innovation and the communication Clean Energy to all Europeans (including the annexes) are guiding documents in this regard.

the threat is. It helps prioritise policy responses and targets efforts to increase the resilience of critical supply chain components.

The broad-brush review will identify the key energy technology sub-families, and assess their impact on three criteria: Critical dependence, EU security of energy supply and EU energy technology leadership. Criteria have been defined so that this assessment can be made objectively using a combination of systematic literature review and expert analysis. Each energy technology will be scored using a standard scoring guide for each of the criteria so that the most appropriate energy technologies for detailed assessment can be identified.

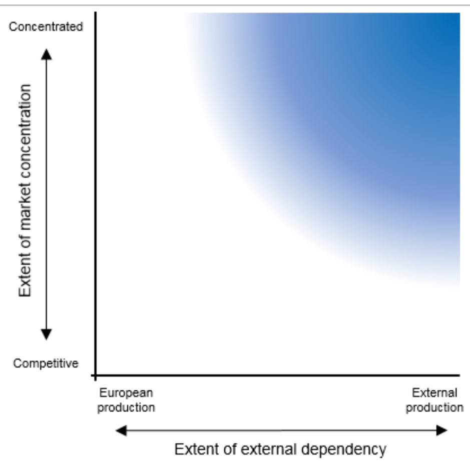
As for the broad-brush analysis, the detailed assessment will also involve a combination of literature review and expert judgement. To ensure that the detailed assessment is comprehensive a value chain map will be created for each energy technology. This will enable a preliminary identification of possible technology dependencies which will be assessed by experts to identify the most significant dependencies. By plotting the extent of market concentration against the extent of external supply, the critical dependency will be established (see below).

***Assessing dependency***

A critical dependency is primarily measured using two parameters:

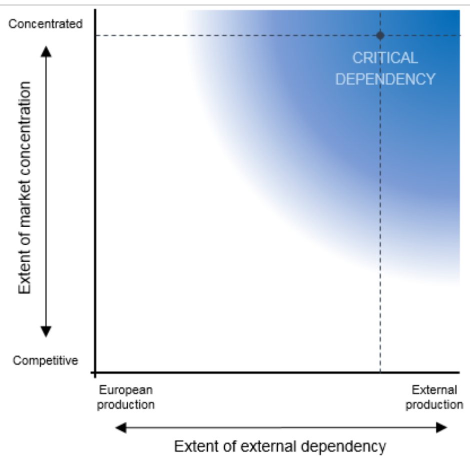
1. The extent of the external dependence
2. Market concentration which gives either supplier firms or countries market power

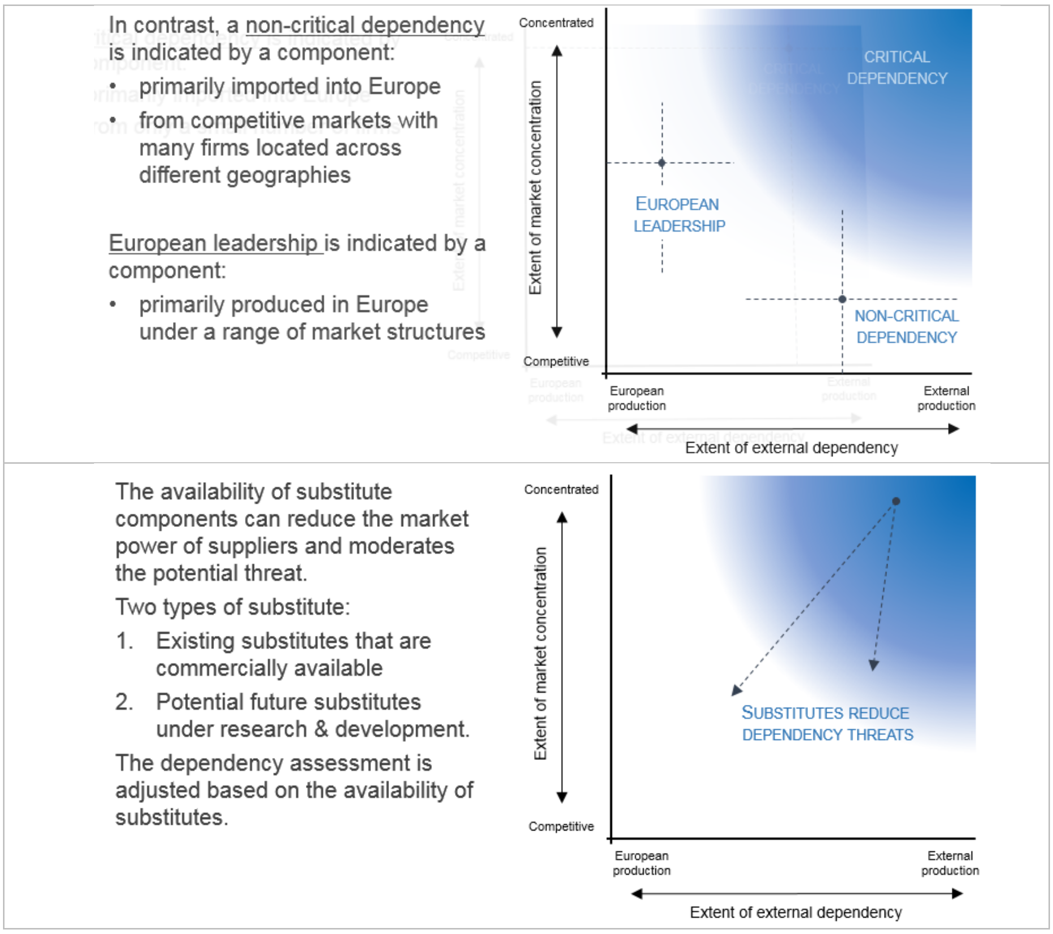
This is presented on a 2-axis grid.




A <u>critical dependency</u> is indicated by a component:

- primarily imported into Europe
- from only a small number of firms






The step-by-step manual has been developed (Chapter 3) and the expert training for the broad brush assessments has been carried out (Chapter 4). The project was presented at the Advisory Group Energy (Chapter 5). The next steps including the broad brush assessment are summarised in Chapter 6. Chapter 7 provides a bibliography.

More detail is provided in the appendices:

- Appendix 1 – Literature review spreadsheet;
- Appendix 2 – Collated literature review;
- Appendix 3 – Further information on methods of assessing dependence;
- Appendix 4 – Further information on value chain mapping;
- Appendix 5 – Glossary of definitions;
- Appendix 6 – Didactical materials;
- Appendix 7 – Broad brush methodology;
- Appendix 8 – Broad brush pilot case template;
- Appendix 9 – Detailed methodology;
- Appendix 10 – Broad brush pilot cases;
- Appendix 11 - Literature search tracker pilot;
- Appendix 12 – Broad brush data sets;
- Appendix 13 – Broad brush methodology: step-by-step manual;
- Appendix 14 – Broad brush methodology: training sessions;
- Appendix 15 - Summary report presented to the Advisory Group Energy (AGE) meeting.

# 1 Definition of the issues (Task 1)

## 1.1 Scope and objectives (Task 1)

The overall objective of Task 1 was to define key concepts, relevant issues, and potential indicators; Task 1 will lay the foundations for the project.

The D1 report includes a definition of the issue, didactical material for policy makers and civil society (the didactical materials will be translated into French and German when approved), and a glossary of definitions. The following activities have been carried out as part of Task 1:

### *1.1.1 Literature review – existing definitions of dependence (sub-task 1.1)*

Existing literature on dependence was reviewed to ensure that the definition of energy technology dependence, proposed in this study, benefits from:

- Lessons learnt from recent dependence studies carried out in other sectors;
- Consistency with EC's wider policies including the EC's European Energy Security Strategy.

### *1.1.2 Identified issues relevant to technology dependence (sub-task 1.2)*

Issues relevant to technology dependence were identified during the literature review, and were used to shape the direction of the iterative literature review process. The focus of the study was to consider technology dependence primarily in terms of external dependencies of the EU. The secondary focus was to consider EU technology leadership.

Metrics to measure technology dependence were identified with a focus on those which are forward looking and which attempt to capture the deep uncertainty in prediction of the future. Inherent to technology dependence problems is that they will reveal themselves in complex, non-linear and emergent circumstances.

### *1.1.3 Investigating how dependencies will be addressed (sub-task 1.3)*

Methodologies to assess energy technology dependence were also investigated.

### *1.1.4 Finalisation of key definitions (1.4)*

A definition of energy technology dependence is proposed based on the outcome of the literature review process. This includes an explanation of key factors considered when defining energy technology.

A range of terms are collated and defined in a glossary. This is the standard language for this study.

### *1.1.5 Preparation of didactical material (sub-task 1.5)*

Didactical materials have been produced which are intended for policy makers and civil society (these will be translated into French and German once approved). This document explains the concepts and definitions in terms that a wide range of policy makers and readers in civil society will find quick and easy to understand. It has been designed for web publication and conforms with EU branding guidelines.

## 1.2 Literature review methodology

A systematic literature review was carried out: this followed a set process and utilised standardised templates. A summary of sources reviewed can be found in Appendix 2.

Standardised templates were used to document the literature review:

- Literature review template (word document): provides a framework for systematically documenting relevant information gathered from each piece of literature reviewed;
- Literature review tracker (excel document): provides a structure for recording literature review templates by catalogue (e.g. by information type, topic, sector, and region of relevance), score (e.g. each piece of literature is scored out of 5 based on literature relevance and credibility), and details of the source (e.g. title, author, data, etc.). The completed version of this spreadsheet is provided as Appendix 1.

The initial wave of the literature review focused on sources stated in the proposal, and those suggested by consortium members. The focus of the literature review evolved as definitions of technology dependence and understanding of preferred methods of assessing technology dependence were established. Furthermore, the literature review was carried out as an iterative process and focused on filling knowledge gaps.

All literature reviewed was entered into the Literature Review Tracker spreadsheet; where each source was catalogued by: type of information; topic; relevant sector; region of relevance; type; and date.

In the literature review template, sources were scored using two scoring criteria: relevance and credibility. A high score (e.g. the highest is 6) indicates a source which is both highly relevant to the scope and focus of the literature review and is from a highly credible source (see Table 1).

**Table 1 Scoring matrix**

| | | Credibility | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Relevance | 1 | 2 | 3 | 4 |
| | 2 | 3 | 4 | 5 |
| | 3 | 4 | 5 | 6 |

The scoring criteria for "relevance" are based on our current understanding of key topics within the scope and focus of this literature review and which align with the purpose of the literature review (section 1.1.1). The proposed initial scoring criteria for "relevance" is detailed in Table 2. The scoring criteria for "relevance" will be revised, as necessary (e.g. if revisions to the scope and focus of the literature review are made (see step one above)).

**Table 2 "Relevance" and Credibility scoring criteria by information type**

| Criterion | Score | Description |
|---|---|---|
| Relevance | 1 | Unlikely relevant to our work. |
| | 2 | Partially relevant to our work. |
| | 3 | Directly relevant to our work. |
| Credibility | 1 | e.g. not peer reviewed |
| | 2 | |
| | 3 | e.g. Official standard (e.g. BSI), Internationally recognised publication |

## 1.3 Literature review

Technology dependence at EU level has previously been assessed for other sectors (e.g. Defence and Space sectors). The literature review sought existing expertise (i.e. relevant studies and papers) related to the topic of energy technology dependence. 72 sources were reviewed using the methodology described in section 0. Summaries of 46 key sources can be found in Appendix 2 and further detail on the proposed relevance and credibility of each source can be found in Appendix 1.

This section provides a summary of best practices and issues evident in the relevant studies. Best practice from previous technology dependence studies was applied to this project and adapted where necessary.

### *1.3.1 Understanding the definition of energy technology dependence*

A variety of issues relevant to energy technology dependence are well understood. This section summarises key information from the literature review used to inform the recommended definition of energy technology dependence proposed in this study. The recommended definition is given in Section 1.4.1 'Proposed definition of Energy Technology Dependence'.

*Energy Security*

There are parallels between the definition of energy security and energy technology dependence; definitions of energy security (see Box 1) provide helpful insight into the definition of energy technology dependence with respect to its scope. The implication is that dependence issues can be defined as related to both *physical unavailability* and *price increases*.

**Box 1 Examples of definitions of energy security**

| |
|---|
| "The loss of economic welfare that may occur as a result of a change in the price or availability of energy'' (IEA 1996) (Winzer, 2010)<br><br>"adequate supply of energy at a reasonable cost" (IEA 1985) (Winzer, 2010)<br><br>"energy security always consists of both a physical unavailability component and a price component, (but) the relative importance of these depends on market structure" (IEA, 2007) (Winzer, 2010)<br><br>"A security of supply risk refers to a shortage in energy supply, either a relative shortage, i.e. a mismatch in supply and demand inducing price increases, or a partial or complete disruption of energy supplies" (Scheepers, Seebregts et al., 2006: p. 13) (Winzer, 2010)<br><br>"situations when energy markets do not function properly and should be mostly aimed at making markets work" (Månsson, Johansson, & Nilsson, 2014) |

A further implication is that barriers to open and competitive markets should be defined as a technology dependence issue.

The definitions of energy security also contain components of both short-term (operational) and long-term (adequacy) threats to energy supply disruptions. The equivalent definitions for energy technology dependence primarily refer to long term threats (adequacy of supply) and only include short-term threats (operational) where there is a renewable fuel component or a key component/service is required for operation and maintenance.

Most definitions of energy security do not articulate absolute thresholds for the threat level, e.g. by how much prices need to increase to be considered a threat to security (Månsson, Johansson, & Nilsson, 2014). More typical is a relative level of threat, which is shown by tracking trends or comparisons. A similar approach is likely to be required for energy technology dependence.

*Criticality*

Criticality is analogous to dependency, where the criticality of materials is defined as those materials with the most acute combination of supply concerns combined with a high economic importance in Europe (Oakdene Hollins; Fraunhofer, 2013).

Critical supply chain elements are resources that are fundamental to a technology which would have the most significant effect on the use of the technology should there be restrictions on access to that resource (ARUP, 2014). An example of a methodology used to identify critical supply chain elements is given in Appendix 3.

(Burbiel & Schietke, 2013) defines **critical technology** as "any technology (including equipment, skill, system, service, infrastructure, software or component) that is required by any organisation with a legal or contractual responsibility for security of citizens in Europe to properly perform its duties.”

*Bottleneck (Lehner, Rastogi, Sengputa, Vuille, & Ziem, 2012)*

A bottleneck is considered to be a constraint at any point along the entire physical supply chain of a technology (e.g. wind or photovoltaic technologies), from the source of raw materials all the way to end-of-life of equipment that significantly reduces the scale of development, deployment or operation of the technology (Lehner, Rastogi, Sengputa, Vuille, & Ziem, 2012). A constraint which is identified as a barrier to deploying projected technology deployment levels (e.g. EU 2050 RE targets) could be considered as a bottle neck (Lehner, Rastogi, Sengputa, Vuille, & Ziem, 2012). An example of this methodology is given in Appendix 3.

*Dependence and non-dependence*

External dependency risk is the risk posed by reliance on other organisations with different strategies and stability. A program’s level of dependence on an external organisation is one component of external risk. If a target/objective (e.g. space mission) cannot succeed without the external organisation, the mission is wholly dependent on it. If the external organisation plays a part but achieving the target/objective is not reliant on it, then the risk to the target/objective is lower (Gerstein, et al., 2016).

“Independence” would imply that all needed technologies are developed in Europe. Whereas “non-dependence” refers to the possibility for Europe to have free, unrestricted access to any required technology (European Commission , ESA, European Defence Agency, 2015).

The ESA (European Commission , ESA, European Defence Agency, 2015) has outlined criteria for defining European Non-Dependence, in the context of the EU space sector, which are stated as follows:

1. Items shall be of low integration level, i.e. building blocks and components (System/sub-system assembly, methods and tools are not included);
2. Items shall have a clearly identified function and performance target;
3. Items shall be multi use and/or applications (i.e. not an enabling technology for a one shot use);
4. Items shall be not available from a European source and for which the unrestricted availability from non-European suppliers cannot be assured;
5. Critical items for which no adequate or sufficient action is ongoing.

**Box 2 Examples of definitions of dependence**

- "Vulnerability to export restrictions that limit their access to these materials and that can result in two-tier pricing, under which domestic manufacturers in the producing country have access to materials at lower prices than those charged for exports, thereby hindering the international competitiveness of U.S. manufacturers and creating pressure to move manufacturing away from the U.S. and into the producing country." (Silberglitt, Bartis, Chow, An, & Brady, 2013)
- For national security purposes, "(1) a foreign source is a source of supply, manufacture or technology outside the United States and Canada; (2) a foreign dependency refers to a source of supply for which there is no immediate available alternative in the United States or Canada; and (3) foreign vulnerability, related to foreign dependency, refers to a source of supply whose lack of availability jeopardizes national security by precluding the production, or significantly reducing the capability, of a critical weapons system." (US National Research Council, 1995)

*Market power*

The EU Merger Regulations provide the basis for competition policy at the European level and they define market power, or control, as conferring the possibility of exercising decisive influence over an undertaking[2].

### *1.3.2 Relevant studies on dependence*

There is a wealth of studies relevant to issues of dependency and closely associated concepts like bottlenecks or criticality (see section 1.3.1 for definitions of bottlenecks and criticality). These studies are primarily concerning material security, supply chains and foreign dependency in the defence and space sectors.

These have been reviewed and show that a wide range of approaches and methods have been used for dependency assessment, which is reflected in the diversity of definitions shaping the key assessment criteria. *Good Practices of Technology Needs Assessments (TNA)* (UNFCCC TEC, 2015) describes the methods used across 36 countries (between 2009 and 2013) for determining country energy technology priorities. The methods include a variety of techniques including expert interviews (used in 80% of the methods), desk study (50%) and 'market mapping' and 'problem trees' (70%) showing the use of mixed methods reflected in much of the literature.

Leading examples of methods for assessing dependence are provided in Appendix 3. Note that these examples were key to the development of the dependence assessment methodology proposed in this report.

Literature has been characterised by the types of methods employed, the use of data and metrics, and the role of expert judgement. Some of the key distinctions identified are principally as a result of:

- The basis for prioritisation;
- The time horizon of the study;

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

- The role of experts in the assessment;
- The scope of the dependency assessment.

Each of these is looked at in turn below to give insight into the best methods for energy technology dependency assessment.

#### 1.3.2.1 Basis for prioritisation

The EU Critical Raw Materials study (Oakdene Hollins; Fraunhofer, 2013) recommends the use of market concentration in future analysis. The economic impact of a supply disruption was also considered as a potential basis for prioritising dependency. Price volatility was used as a proxy which is linked to the elasticity of supply and demand. However, it was not recommended because it is a backward-looking metric. This is arguably a bigger concern for its use as an energy technology dependence indicator. Technological change is rapid and substitution of components/new methods is likely to make historic volatility a less meaningful metric.

(Silberglitt, Bartis, Chow, An, & Brady, 2013) provides details of a method for identifying reliance on imported raw materials needed for manufacturing. The overall approach is to analyse the extent to which the production of important materials is controlled by one or a few nations and how that control can create uncertainty or disruption in supply. The method steps include:

1) Assessing reliability of supply based on production, trade, and commercial and peacetime use data;
2) Market concentration (e.g. using Herfindahl-Hirschman Index- HHI);
3) Analysis of current and potential effects.

The relative importance of the raw materials identified was then prioritised according to how difficult it would be to substitute without significantly increasing the cost or decreasing the performance of the products required.

#### 1.3.2.2 The time horizon of the study

Studies with a shorter time horizon are typically more specific in their assessments and are able to directly identify actions in relation to individual component dependencies. This appears to be because of the improved ability to forecast and predict and the reduced uncertainty.

For example, *Critical Space Technologies for European Strategic Non-Dependence* (European Commission , ESA, European Defence Agency, 2015) has a < 5-year time horizon and used experts to identify critical components and set actions, responsibilities and deadlines for resolution. A review of decommissioning capacity in relation to North Sea oil and gas facilities (ARUP, 2014) conducted its analysis over a 5 to 10-year period. This allowed much greater foresight of activity, technology availability and costs.

Studies with a longer time horizon are more likely to employ metrics which attempt to identify the conditions within which threats to supply may occur, rather than attempting to predict any specific cause of disruption. This appears to be an explicit recognition of the deep uncertainty in predictions of the future and is more appropriate given the inherent challenge where dependency issues are revealed in complex, non-linear and emergent circumstances.

For example, the *Study on Critical Raw Materials at EU Level* (ARUP, 2014) makes its assessment based on a combination of potential supply chain risks combined with the relative economic importance of the raw material in Europe.

Longer term studies also define findings in relative terms, with components more or less critical relative to others rather than applying defined thresholds.

Given this, the methodology employed should take advantage of existing frameworks for making decisions under the deep uncertainty that characterises future energy technology security threats. Flexibility, resilience and keeping options open can all help deal with these fundamental constraints and can be reflected in the metrics used. It should be forward-looking and it should seek to identify dependencies across the whole technology value chain.

#### 1.3.2.3 The role of experts

The majority of studies reviewed make use of the informed judgement of experts at some point in the assessment method. The role can include:

- Early stage screening;
- Assessing evidence gathered to identify priorities;
- Identification, assessment by consensus and prioritisation;
- Use of expert judgement where data is lacking (Oakdene Hollins; Fraunhofer, 2013).

A range of uses of expert input as part of dependency assessment methods have been reviewed. It was found that there are links between time horizon and the use of experts:

Long-term military planning studies provide some insight into the predictability of geopolitical and trade issues to the 2030 and 2050-time horizon. They indicate that analysis of current trends and the informed judgement of experts are helpful in the near term but are of limited use over a longer planning horizon.

This is attributed to two biases in the planning process. The first is that it is not possible to judge the probability of future events in distant time periods. The second is that today's experts have been found to have almost no ability to predict where, when, and how any international dependency issue might arise in 30 years' time.

> *'Assessing the probability of events is difficult to do in the short term; over a multi-decade period, such judgments have little predictive value.'*

As a result, the finding is that 'unforeseen crises or conflicts' are the primary driver of changes in the long-term. The implication for this energy technology dependency study, as stated in an earlier section, is that threats will reveal themselves in complex, non-linear and emergent circumstances and that reliance on the long-term predictions of individuals should be avoided.

The study S*ecuring the solar supply chain for wind and solar energy RE-SUPPLY* (Lehner, Rastogi, Sengputa, Vuille, & Ziem, 2012) looks toward 2025 and 2050 and highlights the challenges faced when expecting stakeholders to provide expert insight over distant time horizons. Bottlenecks were identified through literature review followed by discussions with around 40 industry experts. The recommendations produced generally relate to the near term period (2-6 years) which is closer to their natural foresight and business planning periods than the study time horizon.

The *Evaluation of Critical and Emerging Technologies for the Elaboration of a Security Research Agenda (ETCETERA)* project (Burbiel & Schietke, 2013) assessed technology dependence in the security sector in Europe. It made use of experts combined with structured literature view, including consensus-making in the selection of "Critical Technology" using the World Café Method. Expert judgement was also used in multi-factor evaluation of dependency and in identifying and prioritising emerging technologies. It should be noted that the project focussed on current and near term issues (10-15 year).

#### 1.3.2.4 The scope of the dependency assessment

The *RE-SUPPLY* study (Lehner, Rastogi, Sengputa, Vuille, & Ziem, 2012) is the most closely related study identified with its focus on 'supply chain bottlenecks' in the energy sector. While it has been a key resource, it differs in the scope of the assessment. Because it has a global scope, it does not have an internal/external axis, equivalent to EU/Rest of World. Trade and geopolitics are likely to be drivers of key dependency risks and they are poorly accounted for. The impact of including internal barriers in the scope can be seen in the policy recommendations which include such things as training and planning policy constraints. These can be considered to be within the control of the EU and EU member states.

### *1.3.3 Metrics for assessing dependence*

This section provides insight into relevant metrics used in other studies to define and assess dependence. Potential measures for each metric are also summarised in this section.

The US National Research Council (US National Research Council, 1995), provides insight into the impact of a variety of factors on production related dependence risk (see Table 3 and Table 4 below). This is a useful basis for defining metrics used for the dependency assessment methodology proposed in this study.

**Table 3 Factors when evaluating short-term, production-related component/equipment dependence risks (US National Research Council, 1995)**

| Factors | Low Risk | High Risk |
|---|---|---|
| Criticality of system mission | Noncritical | Critical |
| Mobilization/surge production requirement | Low | High |
| Number of suppliers | Numerous | Few/one |
| Proximity of suppliers to each other | Dispersed | Few/single country |
| Proximity of suppliers to the United States | Nearby | Distant |
| U.S. political relationship with supplier government | Stable | Unstable |

**Table 4 Factors in evaluating long-term technology and manufacturing base component/equipment dependence risks (US National Research Council, 1995)**

| Factor | Low Risk | High Risk |
|---|---|---|
| Criticality of technology | Low | High |
| Motivation of suppliers | Competes with U.S. user | Does not compete |
| Entry barriers | Low | High |
| Acceptable substitutes | Yes | No |
| Reliable legal sanctions for anticompetitive behaviour | Yes | No |
| Number of suppliers | Numerous | Few/one |
| Proximity of suppliers to each other | Dispersed | Few/single country |
| Supplier dependence on U.S. customers | Meaningful interdependence | Supplier not dependent |
| Market | Commodity | Growing rapidly |
| Technological/business spill overs | Significant | Not significant |

#### 1.3.3.1 Extent of dependency

The extent of EU dependency on non-EU countries can be measured using a variety of European net trade statistics (e.g. production data) and market intelligence such as market reports. A variety of dependency assessment methodologies have been reviewed suggesting useful measures.

A study carried out by RAND (Silberglitt, Bartis, & Brady, Soldier-Portable Battery Supply Foreign Dependence and Policy Options, 2014) assesses the risks associated with a foreign-dependent battery supply chain balanced against other supply chain risks and the costs of risk mitigation. It looks at domestic potential to increase domestic production to meet domestic demand in the case of reduced foreign imports, increased demand or other disruptions.

The US Chamber of Commerce Institute (Institute for 21st Century Energy ; U.S. Chamber of Commerce, 2016) provides a set of 20 metrics that can be used to score a country's energy security. These metrics have been reviewed and their potential use for measuring extent of dependence, in the context of energy technology dependence, has been suggested (see Table 5).

**Table 5 Summary of metrics to score countries energy security (Institute for 21st Century Energy ; U.S. Chamber of Commerce, 2016) and suggested applications for measuring extent of energy technology dependence.**

| Metric from (Institute for 21st Century Energy ; U.S. Chamber of Commerce, 2016) | | Potential use for measuring extent of dependency | |
|---|---|---|---|
| Metric category | General description of the metrics | Similar metric | Description of metric |
| Fuel imports | Measure the exposure of the national economies to unreliable and concentrated supplies of oil and natural gas, | Aggregated technology imports | Exposure to unreliable and concentrated supplies of element (e.g. component, raw material) within a technology |

| | | | |
|---|---|---|---|
| | and coal.<br>Higher supply reliability and diversity and lower import levels mean a lower risk to energy security. | | family (e.g. solar PV). |
| Electric power sector | Measure indirectly the reliability of electricity generating capacity. Higher diversity means a lower risk to energy security. | Technology generation capacity compared to total generation capacity | Measure of the importance of a specific energy technology in meeting EU demand. |

JRC's study on critical raw materials (ref #45) provides a useful approach to assessing import dependency. It suggests that when the extent of dependency is high (e.g. reliance on an element imported almost entirely from non-EU countries) that there should be reason for concern. The study estimates dependency on imports based on EU level annual data on primary production and net imports using the following equation: Import dependence = Net imports / (Net imports + EU production).

There are a range of other established measures, used across a variety of studies, which have been considered as measures of EU dependency, and potential for substitutability (see Table 6).

**Table 6 List of measures**

| |
|---|
| Technology readiness level (TRL) (European Commission , ESA, European Defence Agency, 2015) |
| Commercial readiness index (CRI) (ARENA, 2014) |
| Number of restricted export licences (European Commission , ESA, European Defence Agency, 2015) |
| Production (in units) (European Commission , ESA, European Defence Agency, 2015) |
| Sales (in units) (European Commission , ESA, European Defence Agency, 2015) |
| Intellectual property rights e.g. IPR, through patent analysis (Burbiel & Schietke, 2013) |
| Trade and academic restrictions through analysis of publicly available legal texts (Burbiel & Schietke, 2013) |
| European and global market size |
| Import, export and demand |
| Innovation readiness levels (IRL) (KIC InnoEnnergy, 2014) |

#### 1.3.3.2 Market concentration

Market concentration reflects the number and size distribution of firms in an industry. The market is more competitive when it is formed of many companies with low market share. When the market is dominated by only a few larger firms the market is concentrated which gives them market power. The EU Merger Regulations, the basis for competition policy at the European level, defines market power, or control as 'Conferring the possibility of exercising decisive influence over an undertaking[3]. Market concentration creates the conditions for the abuse of market power and the ability to restrict output and withhold supplies and thereby raise prices, and to reduce quality.

In appraising market concentration, the European Commission takes into account both single-firm dominance and collective dominance, where an oligopoly results in parallel market conditions which can result in anti-competitive behaviour. Both single-firm and collective dominance provides opportunities for tacit collusion by the members. The factors taken into account in assessing concentrated market structures include product homogeneity or the similarity of substitutes, barriers to market entry, low buyer power and lower levels of technological change. This last point is in recognition of the fact that markets where innovation is important are less likely to be anti-competitive due to the big potential benefits from competing with rivals rather than colluding at the firm-level. This may mean that firm-level market concentration could be more important for lower innovation value chain steps and country-level market concentration where innovation is high.

The extent to which supplier markets are concentrated is a key aspect of assessing external dependency. There are a range of established measures that can be used to assess market concentration. These are described below.

*Herfindahl-Hirschman Index*

The Herfindahl-Hirschman Index (HHI) is a standard measure of the concentration of market power. It is used by the EC DG Competition and the US Department of Justice in their anti-trust guidance as a metric which can trigger concern about the potential for excessive market power in relation to mergers and acquisitions.

The HHI can be seen as a standard index of concentration and it is the most often used in anti-trust analysis. It is given by the sum of the squared market shares of the firms in the market and can vary between 0 and 10,000 (or between 0 and 1 if fractions are used). A value of 0 implies that the market is entirely fragmented and a value of 10,000 means that there is only one firm which has 100% of the market (Oakdene Hollins; Fraunhofer, 2013)

The HHI method can be extended to measure country concentration as well as corporate. For example, in (Oakdene Hollins; Fraunhofer, 2013), the HHI is used as a measure of corporate concentration. This is important because dominant producing companies may be able to exert significant market power, such that they can manipulate the end-user prices through strategic reductions in supply or price-fixing mechanisms. More widely, such collusive behaviour by firms and the resulting impact on prices are of concern even for important producing countries like China.

The (Oakdene Hollins; Fraunhofer, 2013) study provides an example of where the HHI has been modified to take into account country-level production with an indication of poor

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

governance or low environmental standards. In this case, country-level data on production is provided quantitatively, using a variety of sources. Poor governance and low environmental standards are indicated by the World Governance Index (WGI) and the Environmental Performance Index (EPI) respectively.

The European Commission has produced a simplified procedure for assessing competition in a more streamlined way for some horizontal mergers[4]. Competition concerns are raised when the aggregate HHI following the transaction is above 2,000, subject to other considerations.

The US Department of Justice also uses market concentration indicators alongside other evidence of competitive effects when assessing the competitive effects of a merger[5]. They also use HHI to assess market concentration. Different threshold classifications are used but can be grouped as:

- Un-concentrated Markets: HHI below 1000-1500
- Moderately Concentrated Markets: HHI between 1000 and 2500
- Highly Concentrated Markets: HHI above 1800-2500

The thresholds are not identified as rigid levels but as indicators of situations where further assessment is required. It may be challenging to collect the data necessary for the HHI up to the standard of the EC or US DOJ guidance for this assessment.

*Concentration ratio*

An alternative measure for market concentration is the concentration ratio. This measure uses only the industry output of the largest firms in the market and assesses their combined total market share. Expressed as CR(n), two common versions are:

- CR4: The Four-Firm Concentration Ratio measures the total market share of the four largest firms in an industry.;
- CR8: The Eight-Firm Concentration Ratio measures the total market share of the eight largest firms in an industry.

The classification of results will depend on the number of firms included in the calculation but can be placed into broad groups, such as:

- Low concentration and highly competitive - 0% to 50%;
- Medium concentration - 50% to 80%;
- High concentration and potential oligopoly or monopoly - 80% to 100%.

A limitation of the concentration ratio is that it does not consider the distribution of output among the largest firms, nor does it provide more nuanced insight into the market structure and competition.

[4] http://www.eversheds-sutherland.com/global/en/what/articles/index.page?ArticleID=en/Corporate/European-Commission-Merger-Simplification-Regulatory-Burden-Reduction-Initiative
[5] https://www.justice.gov/atr/horizontal-merger-guidelines-08192010#5c

US defence studies on foreign dependency identify concentration ratio thresholds which indicate potential threats. (Moran, 1990) identifies a CR4 of 50% as the critical threshold for the creation of oligopoly strength:

> *'If four actors control less than 50% of a market, the difficulties of collusion overwhelm their ability to coordinate policy even if they share common objectives' (Moran, 1990)*

### *1.3.4 Forecasting Methods*

A summary of different types of forecasting methods taken from (National Research Council, 2003) is provided in Table 7 below. Further to the discussion in 1.3.2, long term forecasting methods have not been deployed in the dependency assessment methodology proposed in this study. However, methods like the Delphi method have been used to inform the use of expert input in eliciting expertise on key dependencies in the short term.

**Table 7 A summary of different types of forecasting methods from (National Research Council, 2003)**

| Judgemental or intuitive methods | |
|---|---|
| **Type** | **Notes** |
| The Delphi Method | Structured approach to eliciting information from groups of experts, with an emphasis on producing an informed consensus.<br><br>Pros: can cover a wide variety of topics; topically flexible; relatively easy to carry out. |
| Extrapolation and trend analysis | |
| **Type** | **Notes** |
| Trend Extrapolation | In trend extrapolation, data sets are analysed with an eye to identifying relevant trends that can be extended in time to make predictions. |
| Gompertz and Fisher-Pry Substitution Analysis | New technologies tend to follow a specific trend as they are deployed, developed, and reach maturity or market saturation. This trend is called a growth curve or S-curve.<br><br>Uses historical trend data to predict when products are nearing maturity and likely to be replaced by new technology. |
| Analogies | Forecasting by analogy involves identifying past situations or technologies similar to the one of current interest and using historical data to project future developments. |
| Morphological Analysis (TRIZ) | The technique lends itself to forecasting in that it provides a structured process for projecting the future attributes of a present-day technology by assuming that the technology will change in accordance with the Laws of Technological Evolution. |
| Models | |
| **Type** | **Notes** |
| Theory of Increasing Returns | Applying the usual laws of economics is often sufficient for forecasting the future behaviour of markets. However, modern technology or knowledge-oriented businesses tend not to obey these laws and are instead governed by the law of increasing returns. |
| Chaos Theory and Artificial Neural Networks | What chaos theory reveals, especially through bifurcation patterns, is that the future performance of a system often follows a complex, repetitive pattern rather than a linear process. |
| Influence Diagrams | An influence diagram (ID) is a compact graphical and mathematical |

| | |
|---|---|
| | representation of a decision situation. In this approach, the cause-effect relationships and associated uncertainties of the key factors contributing to a decision are modelled by an interconnection graph, known as an influence diagram |

#### 1.3.4.1 Technology innovation systems

This is a concept developed to explain the nature and rate of technological change. The method of analysis focuses on existing technologies (from pre-development to stabilisation). A technology innovation system can be defined as the set of actors and rules that influence the speed and direction of technological change in a specific technological area (Hekkert, Negro, Himericks, & Harmsen, 2011)

This method is broken down into the steps below (See Appendix 3 for further detail) (Hekkert, Negro, Himericks, & Harmsen, 2011):

1) **Structural analysis.** Breakdown innovation system components which can include actors, institutions, networks and technological factors;
2) **Determining the phase of development** of the technology being analysed;
3) **Identifying system functions.** System functions include:
    - Entrepreneurial experimentation;
    - Knowledge development;
    - Knowledge exchange;
    - Guidance of the search;
    - Formation of markets;
    - Mobilization of resources;
    - Counteracting resistance to change.

    There will be different functional patterns (order of functional path), depending on the stage of the technology (e.g. pre-development or stabilisation);
4) **Analysis.** Analysis of functions to determine which pose the largest barriers. In (Moran, 1990), analysis is based on indicators and a list of diagnostic questions against each function. The output of the analysis is the rating of each function using the lkert scale (illustrated on a spider-diagram);
5) **Structural cause for functional barriers;**
6) **Obstacles for policy goals.**

### *1.3.5 Value chain mapping*

Mapping of an industry is a common starting place to building an understanding of that industry, and is thus an important step in assessing technology dependency. Mapping of value chains is where value chains are produced encompassing all resource and knowledge flows that underpin the sequence of production processes and activities required to bring a product or a service to the market (Todeva & Rakhmatullin, Industry Global Value Chains, Connectivity and Regional Smart Specialisation in Europe, 2016)

A variety of reports have been reviewed which focus on the analysis of global industries (e.g. offshore services (Gereffi & Fenandez-Stark, The Offshore Services Global Value Chain, 2010), offshore decommissioning (ARUP, 2014), energy technologies (JRC, 2013; Moss, Tzimas, Kara, Willis, & Kooroshy, 2011; Brun, Hamrick, & Daly, 2016). The methods of analysis in each of these reports share a common step: to build a comprehensive understanding of the industry in question.

“Top-down” approaches to mapping global value chains (GVC) focus mainly on lead firms and organisations of international industries, and are thus useful for mapping established industry sectors (e.g. energy sector) (Todeva & Rakhmatullin, Global Value Chains Mapping: Methodology and Cases for Policy Makers, 2016). A “bottom-up” approach is useful for mapping capabilities within the GVC that operate at specific locations (Todeva & Rakhmatullin, Global Value Chains Mapping: Methodology and Cases for Policy Makers, 2016). Both methodologies can be applied to emerging sectors and segments driven by key enabling technologies or to cross-sectoral value chains.

Further information on value chain mapping is summarised in Appendix 4.

## 1.4 Key conclusions and recommendations

This section summaries the proposed definition of energy technology dependence as well as key approaches to assessing energy technology dependence informed by the literature review as summarised in section 1.3 above.

### *1.4.1 Proposed definition of energy technology dependence*

The definition of energy technology dependence, proposed in this section, makes a clarifying distinction between the extent of the external dependency and whether this represents a potential threat or not. This is important because this report considers it a fundamental assumption that external dependence is inherent to the globalisation of technology value chains. Broad and diverse competitive markets encourage innovation, exploit comparative advantages between countries, and lower the price of energy technology inputs to the benefit of European interests.

The proposed definition relies upon the observation that a reliance on foreign suppliers is not in itself a threat provided that global markets are free, fair and competitive. Under these circumstances the structure of the market in which the suppliers operate means that companies or countries do not have market power; an ability to restrict output, withhold supplies, reduce quality and thereby to raise prices. Conversely **high market concentration** is where a small number of supplier firms or supplier countries have significant market share, as with oligopoly. It makes firm level collusion or coordination of policy between supplier countries possible and creates the scope for credible threats to withhold supplies during geopolitical or trade disputes.

**Critical dependency** is therefore where the extent of the external dependence is high and where the supplier market is concentrated in the hands of few firms or countries giving them market power and the ability to influence price and availability. The **level of critical dependency** is evaluated with these two parameters (extent of dependence and market concentration).

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 high and where the supplier market is concentrated in the hands of few firms or countries, giving them market power and the ability to influence availability and price.*

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 technology leadership.

Further detail explaining the definition of the proposed metrics to measure energy technology dependence is provided in Appendix 9.

### *1.4.2 Approach for assessing energy technology dependence*

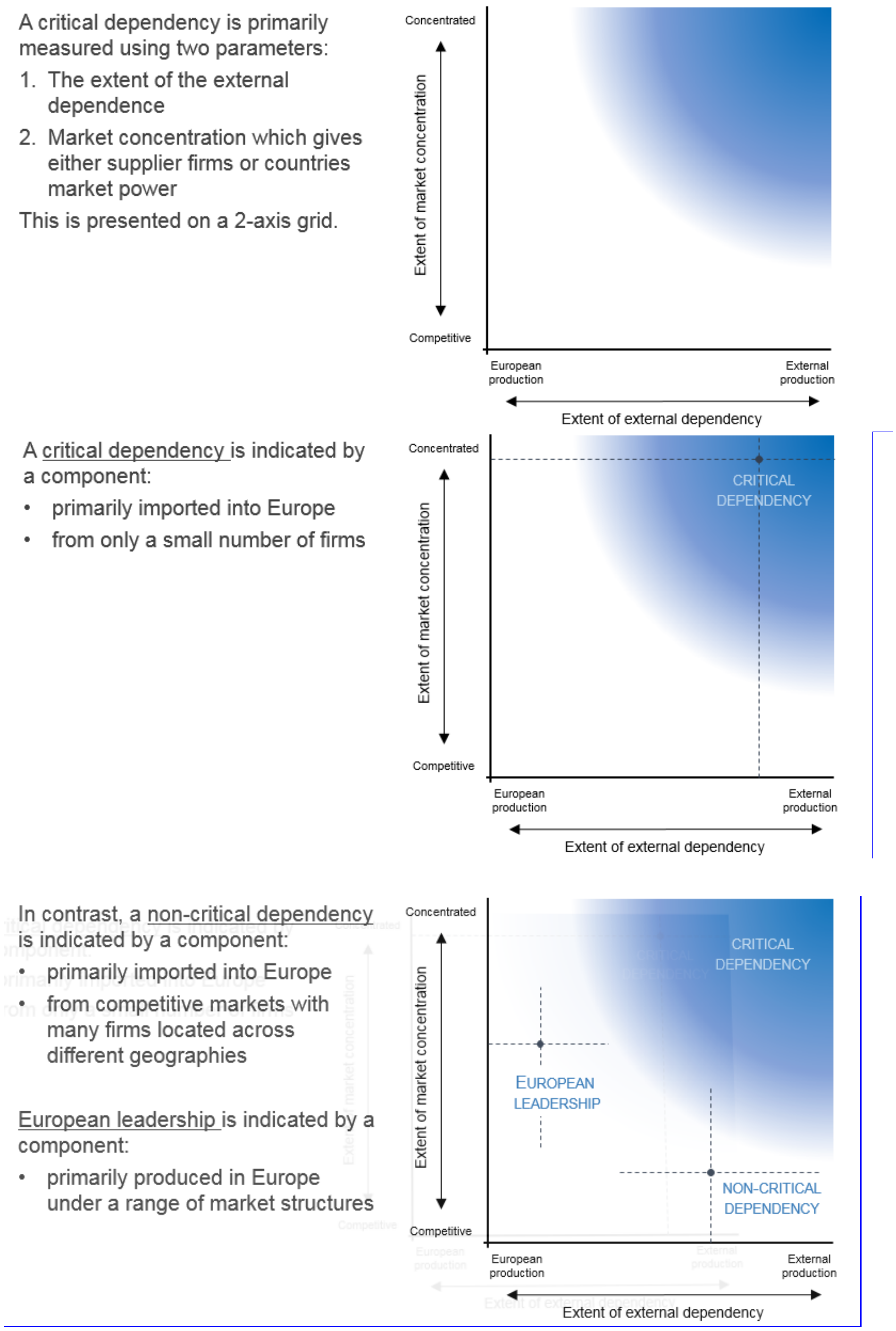
We can't predict the future and threats to our energy infrastructure are hard to predict. Such threats often reveal themselves in complex, non-linear and emergent circumstances. Our assessment takes account of this deep uncertainty by taking a forward looking, non-predictive approach to measuring dependency.

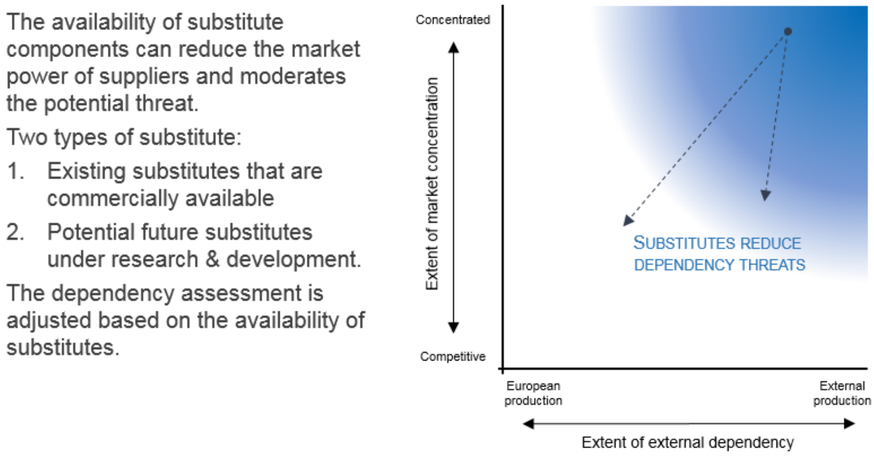
Our approach builds upon dependency and material security studies in the fields of defence, space and critical infrastructure and also the Critical raw materials for the EU study which investigated European dependency on rare earth elements, published in 2014 by the European Commission (Oakdene Hollins; Fraunhofer, 2013). This is the first time a method for assessing energy technology dependence has been developed.

The method identifies the conditions for potential element (i.e. components, services, materials, etc.) dependency and then measures how critical the threat is. It helps to prioritise policy responses and targets efforts to increase the resilience of critical elements.

Appendix 9 provides details of the proposed metrics and methods for assessing technology dependence. As a brief overview of the concluding rational behind the approach, the following figure illustrates how energy technology dependence will be measured, included the proposed metrics.

**Figure 1 Illustration of the proposed metrics for measuring energy technology dependences**






The availability of substitutes must also be taken into account when judging how critical a dependency is. Readily available and reasonable cost substitutes reduce the market power of suppliers and moderate the threat.

The availability of substitutes is central to the ultimate judgement of how critical a dependency is. Where the substitute products are homogenous then they effectively form a single large market with additional supplier diversity. However, even where currently available and reasonable cost substitutes are available, they are unlikely to fully resolve the threat from dependency as there may well be associated costs, decreases in performance and disruption as a result. The transition to a substitute would affect some manufacturers more than others due to the diversity of processes and components already in use. The impact of redesign and retooling will be greater for some and could reduce the overall competitiveness of European firms.

There are two distinct types of substitute:

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

Existing substitutes that are commercially available and potentially already in use in the market will be preferable to potential future substitutes that are still undergoing research and development.
The value of potential future substitutes takes account of its readiness, whether currently in the lab, being tested or pre-commercial.

## 1.5 Glossary of definitions

A glossary of definitions has been compiled using established terms where appropriate. The list of terms used throughout this study are listed in Appendix 5.

## 1.6 Didactical materials

The Didactical materials are provided in Appendix 6.

# 2 Development of a methodology (Task 2)

## 2.1 Scope and objectives

The objective of Task 2 was to develop a methodology for assessing current and future areas of technology dependence. This includes a two phase assessment methodology:

- Broad brush analysis;
- Detailed analysis.

This was achieved by drawing from the output of Task 1, and by carrying out the following activities:

- Collect and review relevant theories on assessment of technology dependence;
- Analyse theories and select applicable methods and techniques for the broad brush and detailed analysis;
- Test parts of the broad brush and the detailed methodology using the pilot case.

Following the development of the assessment methodology, a step-by-step manual will be developed to guide Task 3 and Task 4. Furthermore, training will be provided to technology experts in the consortium to ensure the consistent application of the methodology in Task 3 and Task 4.

The main objective of the broad-brush analysis method is to identify five energy technology families (from the energy technology families identified in the TOR) which are most significant in terms of EU energy security, and which are the most important for the EU's energy technology market leadership goals. These five technology families will then be assessed in detail as part of Task 4.

The key output from the broad brush analysis is the scoring of each energy technology family which will be summarised as described in the full broad brush methodology.

The **detailed analysis methodology will provide instruction** on the:

- Collection and validation of data needed to achieve all objectives and key outputs;
- In-depth analysis of the dependencies and critical dependencies, including looking in detail at each of the energy technology value chains. Analysis will be based on:
    - Supply chain mapping;
    - Literature review;
    - External interviews;
    - Focus groups (attendance by industry representatives; local policy makers; experts from universities or research institutions; EU policy officers);
    - Validation workshops (with six Member States).
- Assessment of risk (impact) that these critical dependencies have on EU security of supply, and a position on whether this risk is expected to increase or decrease over time (i.e. driving forces/factors and ongoing mitigation measures and their expected impact on the identified dependencies);
- Analysis of the factors that influence these critical dependencies along the value chain;
- Structure to provide an overall view of the strengths and weaknesses of the five technologies, in terms of EU leadership.

The detailed analysis methodology will be applied to the five energy technology families identified in the broad brush analysis (Task 3). Furthermore, all analysis carried out will be based on the definitions and metrics/domains identified in Task 1.

The detailed analysis methodology will include the following guidance:

- Clear definitions of metrics and impact levels, etc.;
- Detailed process flow diagrams;
- Indication of roles & responsibilities;
- Interview protocols;
- Survey formats;
- Templates;
- How to guides including: description, goal, activities, results, and strong and weak points of the techniques.

Key **outputs** from carrying out the detailed analysis will include:

- Final "impact (risk)" score, for each of the five energy technology families based on the definition of energy technology dependence and criteria/metrics stated in the methodology;
- Breakdown of key elements contributing to the overall impact (risk), including information on:
    - "Driving forces";
        - Critical dependence rating;
        - Substitutability;
        - Expected change (ongoing mitigation measures, other?)
        - Other considerations?
- Overall view on the importance of each energy technology family for EU leadership.

### *2.1.1 Value chain mapping*

The global value chain (GVC) framework is widely used by academics and practitioners to conduct detailed research on the structure and dynamics of global industries (Frederick, GVC concepts and tools, 2016). The GVC framework focuses on the sequences of value added within an industry, from conception to production and end use. It examines the job descriptions, technologies, standards, regulations, products, processes, and markets in specific industries and places, thus providing a holistic view of global industries both from the top down and the bottom up (Brun, Hamrick, & Daly, 2016).

The *Global Value Chain Analysis: A Primer (Second Edition)* guidance document produced by the Duke Center on Globalization, Governance & Competitiveness (Gereffi & Fernandez-Stark, Global value chain analysis: a primer (second edition), 2016) is a useful starting place for creating a bespoke method to GVC mapping for this project.

JRC provide further guidance in the publication "Industry Global Value Chains, Connectivity and Regional Smart Specialisation in Europe: An Overview of Theoretical Approaches and Mapping Methodologies" (Todeva & Rakhmatullin, Industry Global Value Chains, Connectivity and Regional Smart Specialisation in Europe, 2016).

The reports which focus on the analysis of global industries (e.g. offshore services (Gereffi & Fenandez-Stark, The Offshore Services Global Value Chain, 2010), offshore decommissioning (ARUP, 2014), and energy technologies (JRC, 2013; Moss, Tzimas, Kara, Willis, & Kooroshy, 2011; Brun, Hamrick, & Daly, 2016)) have been reviewed. The methods of analysis in each of these reports share a common step: to build a comprehensive understanding of the industry in question. This is typically achieved by mapping value chains which encompass all resource and knowledge flows that underpin the sequence of production processes and activities required to bring a product or a service to the market. The table below gives some examples which have been used to further guide the development of the approach used in this project.

**Table 8 Examples of the application of the GVC framework**

| Application of GVC framework | Approach / method of categorising |
| --- | --- |
| (Sturgeon, 2013) Understanding availability of data relevant to economic globalisation | GVC. Top-down. Input-output. |
| (Gereffi & Fenandez-Stark, The Offshore Services Global Value Chain, 2010) analysis of offshore services | GVC. Top-down.<br>1) Three main economic activity segments: information technology, business process, and knowledge process.<br>2) Detail added to each segment on services which are provided across the industry (horizontal services) and those which are industry specific (vertical services). |
| (Brun, Hamrick, & Daly, 2016) analysis of utility scale solar PV industry in North Carolina. | GVC. Top-down.<br>1) Value chain into 6 key project phases. With an emphasis on the project developer perspective.<br>2) Detail added on participants/actors for each phase. |
| (Todeva & Rakhmatullin, Global Value Chains Mapping: Methodology and Cases for Policy Makers, 2016) Analysis of global biopharma industry | GVC. Top-down approach complimented by bottom-up approach for building comprehensive bespoke datasets. Focus on Multinational Enterprises (MNEs)<br>1) Categorise industry boundaries using existing categories.<br>2) Build a comprehensive bespoke dataset of firms involved. Use of declared industry codes.<br>3) Categorisation of firms in core value chain groups<br>4) Map industry value chain |

## 2.2 Methodology for assessing energy technology dependence

Overall, there is no single perfect method for assessing technology dependency, as each method has its strengths and weaknesses. Ultimately, the both broad brush and detailed analysis methods meet the aim of this project within the given requirements and availability of data and resources.

The following key points have been considered when selecting the appropriate methods and determining the overall methodology:

- The nature and category of the technologies being assessed, availability of experts and time frames available for the overall assessment;

- Data sources. Data must come from a diverse group of individuals and collection methods and should consist of both quantitative and qualitative data (National Research Council, 2003);
- **Multiple forecasting method.** Combining existing and novel forecasting methodologies (National Research Council, 2003);
- Methods involving expert insight should try to engage a wide variety of researchers, entrepreneurs and technologies, particularly those who understand the technology, and are most likely to be involved in creating innovative technologies within the field;
- Appropriate application of methods, e.g.:
  - Computers are great tools for raw data mining, automated data gathering ("spidering"), statistical computation, data management, quantitative analysis and visualization;
  - Experts are best at pattern recognition, natural language interpretation and processing, intuition, and qualitative analysis.

### *2.2.1 Broad brush methodology*

Appendix 7 contains the broad brush methodology (which was updated following the review of the pilot assessment results). Appendix 8 contains our proposed broad brush pilot case template. Information on the pilot is given in Section 2.3.

### *2.2.2 Methodology for detailed assessment*

In ETD sub-task 4.1, the five energy technologies suggested as a result of Task 3 will be confirmed with "all relevant stakeholders" following the three step approach below.

1. Evaluate results of validation workshop. Identify any pending items that need to be addressed e.g. additional stakeholder that need to be consulted;
2. Follow up on pending items and update the proposed selection of energy technology families accordingly;
3. Agree on the final selection of energy technology families with the Commission.

The detailed methodology is given in Appendix 9.

The detailed methodology still needs further work as follows and this will be done after we receive feedback from the Commission:

- Stages 2 and 3 are lacking detail in some areas (especially Stage 3) and they need more instruction/guidance. This will be developed before the detailed assessment pilot begins. Other parts can be taken directly from the broad brush methodology so we would like feedback on this from the Commission first);
- Templates to accompany the detailed methodology need to be completed. These can be based on the ones used in the broad brush methodology and will be done following feedback on these;
- Improvement/revision of the detailed methodology will be made in parallel with the pilot.

## 2.3 Pilot case results

Appendix 10 presents the results of the two pilots, assessing offshore wind energy and solar PV using the final version of the broad brush assessment methodology, including:

- **Stage 1:** Summary paper on issues of critical dependence relevant to solar PV and offshore wind;
- **Stage 2:** Collated data on indicators of solar PV and offshore wind importance in terms of EU security of supply and EU leadership;
- **Stage 3:** Assessment of each energy technology family against criterion 1, 2 and 3 (i.e. Critical dependence, EU security of energy supply, and EU energy technology leadership.

A description and comparison of the data sources collated for each stage is also included in Appendix 11 and Appendix 12 contains a broad brush template populated during the pilot.

# 3 Step by step manual

Following the review of the pilot assessment results, and in line with feedback on the initial methodologies, a revised methodology was written (Appendix 7). This was used as the basis the step by step manual (Appendix 13). These will be further updated and finalised following feedback gained during the broad brush assessments being carried out (Task 3).

The step by step manuals serve two purposes:

1. To be used in the current project as the standard way to assess dependency for each technology family. This will support the consistent application of assessment techniques and scoring across the broad brush analysis of all energy technology families (Task 3) and detailed analysis of the five selected energy technology families (Task 4).
2. Secondly it will be a document that can be used in future studies.

The manual has been organised in the following way:

- An overview of the purpose of the assessment;
- A summary of the steps (in a process diagram);
- A section on the broad brush analysis: techniques and appropriate data sources;
- A section on the detailed assessment: techniques and guidance on detailed data collection;
- A section on how to identify the key dependencies, and how to present the results.

# 4 Expert training

Training sessions were held at the TNO office in Utrecht and DNV-GL office in Arnhem during the last week in September. These provided an opportunity for the Project Team to review, with the technical experts who will be carrying out the broad brush analysis the:

- Overall purpose of the ETD project;
- Overall project as well as task 3 timeline;
- Relevant progress to date e.g. definition of energy dependence;
- Methodology proposed for task 3 including:
  - Purpose;
  - Process;
  - Expected outputs;
  - Roles;
  - Templates and guidance available.

It also provided an opportunity to discuss potential issues with methodology and identify solutions. The agenda and presentation for these training sessions are provided in Appendix 14.

# 5 Validation workshop

As validation and support for the methodology, we plan to hold a series validation meetings/workshops. Two meetings are planned to present the methodologies to energy academic experts and to practitioners of R&I energy policy in the EC and Member States.

The meetings are as follows:

- SET-plan steering group;
- Advisory Group of Horizon 2020 Societal Challenge.

The aim is to:

- present an overview of the project and the methodology.
- confirm key definitions.
- obtain feedback and buy-in from the groups on the methodology identifying any significant areas for improvement.
- gain support for selecting technologies for detailed assessment.

The meeting with the Advisory Group Energy was held on 10 October. Th summary paper provided for this meeting is provided in Appendix 15.

# 6 Next Steps

The brad brush assessments are being carried out for the 12 energy technology families identified in the Terms of Reference:

**Renewable Energy:**

- Solar Energy (Photovoltaic, concentrated solar power, solar Heating & Cooling);
- Wind Energy (on shore, off shore, floating off shore);
- Hydropower (large and small);
- Bioenergy (biochemical, thermochemical, algae, enzymes);
- Geothermal Energy (dry steam, flash steam, binary steam, enhanced geothermal);
- Ocean Energy (wave, tidal, marine, ocean thermal conversion);
- Hydrogen & Fuel Cells;
- Energy storage (heat, mechanical, chemical and electrical).

**Carbon Capture, Storage and Utilisation, and Clean Fossil Fuels:**

- $CO_2$ capture (pre-combustion, post-combustion, oxy-fuel combustion);
- $CO_2$ storage (depleted gas and oil fields, deep saline aquifers, enhanced hydrocarbon recovery);
- Utilization i.e. re-use of captured $CO_2$;
- Flexible conventional thermal power plants.

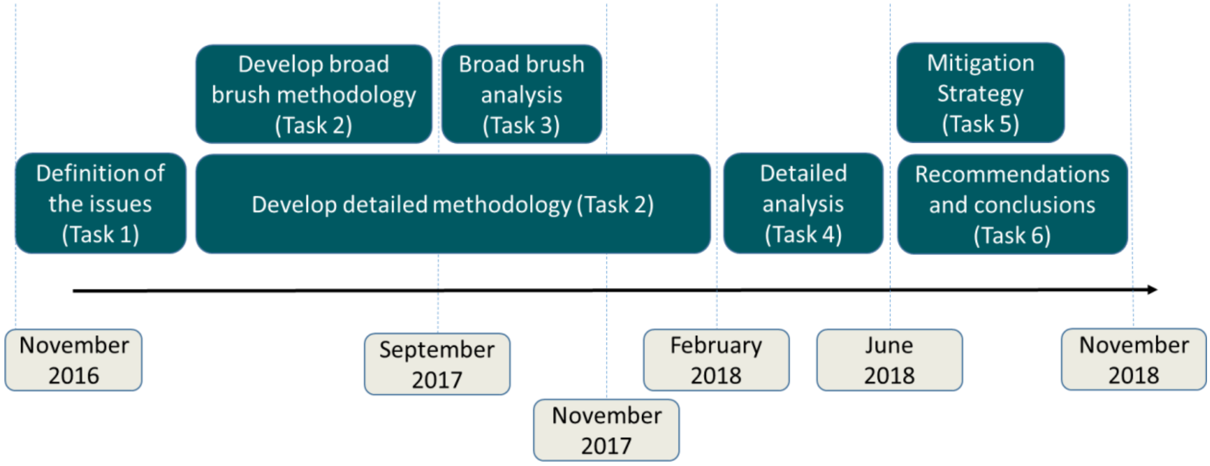
Following feedback from EC and the AGE meeting we are discussing with the EC Project Officer whether it will be possible to extend the scope to include:

**Energy efficiency:**

- Building thermal insulation (phase change materials, dynamic glazing, adaptive façade systems, etc);
- Heat pumps;
- Condensing boilers;
- Cooling supply technologies.

In parallel, the detailed methodology is being further developed. A summary of the tasks required to complete the project is provide in the figure below

**Figure 2 Timeline for tasks to complete the project**



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# List of Appendices



Please note that the Appendices have been provided to the Commission as separate documents for ease of editing and use. They can be requested from the contractor (Trinomics).

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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 interim report of the study and includes the definitions and methodology for understanding and assessing energy technology dependencies.

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