OAKDENE HOLLINS
RESEARCH & CONSULTING

Fraunhofer
ISI

Study on Critical Raw Materials at EU Level

Final Report

Sustainable products and services
Clean technologies
Resource efficiency

A report for
DG Enterprise and Industry

16 December 2013

This report has been prepared by: This report has been jointly prepared by Oakdene Hollins and Fraunhofer ISI

The authors from Oakdene Hollins are Adrian Chapman, Josephine Arendorf, Tecla Castella, Paul Thompson and Peter Willis

The authors from Fraunhofer ISI are Luis Tercero Espinoza, Stefan Klug and Eva Wichmann

Checked as a final copy by: Katie Deegan

Reviewed by: Nick Morley

Date: 16 December 2013

Contact: adrian.chapman@oakdenehollins.co.uk

File reference number: EC—11 315 –Final Report Issue 3.docx

Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Author	Editor
Issue 1.0	15/11/2013	Issue 1.0 for DG ENTR	AC	KD
Issue 2.0	12/12/2013	Issue 2.0 for DG ENTR following comments	AC	PW
Issue 3.0	16/12/2013	Minor revision for DG ENTR following comments	AC	LM

Glossary

AHWG	Ad-Hoc Working Group on defining critical raw materials
APPPC	Asia and Pacific Plant Protection Commission
BGR	German Federal Institute for Geosciences and Natural Resources
BGS	British Geological Survey
BRGM	Bureau de Recherches Géologiques et Minières
CAGR	compound annual growth rate
CEPI	Confederation of European Paper Industries
CR	Concentration Ratio
CRM	Critical Raw Materials
DRC	Democratic Republic of the Congo
ECHA	European Chemicals Agency
EEA	European Environment Agency
EIP	European Innovation Partnership on Raw Materials
EITI	Extractive Industries Transparency Initiative
EPI	Environmental Performance Index
ETRMA	European Tyre & Rubber Manufacturers’ Association
EUBA	European Bentonite Association
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GVA	Gross Value Added
HHI	Herfindahl-Hirschman-Index
HREEs	Heavy Rare Earth Elements
ICA	International Copper Association
ICSG	International Copper Study Group
ICT	Information and Communication Technology
IFA	International Fertilizer Industry Association
ILZSG	International Lead and Zinc Study Group
INSG	International Nickel Study Group
LREEs	Light Rare Earth Elements
MMTA	Minor Metals Trade Association
OECD	Organisation for Economic Co-operation and Development
PGM	platinum group metal
ppb	parts per billion
PPI	Policy Potential Index
ppm	parts per million
PV	photovoltaic
REACH	Registration, Evaluation, Authorisation and restriction of Chemicals
REE	Rare Earth Elements
RGI	Resource Governance Index
RMI	Raw Materials Initiative
RoHS Directive	Restriction of Hazardous Substances Directive
SALB	South American Leaf Blight
STDA	Selenium Tellurium Development Association
SVHC	Substances of Very High Concern (REACH)
TDA	tyre derived aggregates
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environmental Programme
USGS	US Geological Survey
VAT	value added tax
WGI	World Governance Index
WMD	World Mining Data
WTO	World Trade Organisation

Abiotic:	Metals (or metallic ores) and industrial minerals. These are derived from static reserves.
Biotic:	Materials which are derived from renewable biological resources that are of organic origin but not of fossil origin. Only non-energy and non-food biotic materials are under consideration in this report.
Deposit:	A concentration of material of possible economic interest in or on the earth's crust.
Reserves:	The term is synonymously used for "mineral reserve", "probable mineral reserve" and "proven mineral reserve". In this case, confidence in the reserve is measured by the geological knowledge and data, while at the same time the extraction would be legally, economically and technically feasible and a licensing permit is certainly available.
Resources:	The term is synonymously used for "mineral resource", "inferred mineral resource", "indicated mineral resource" and "measured mineral resource". In this case, confidence in the existence of a resource is indicated by the geological knowledge and preliminary data, while at the same time the extraction would be legally, economically and technically feasible and a licensing permit is probable.
Units:	Conventional SI units and prefixes used throughout: {k, kilo, 1,000} {M, mega, 1,000,000} {G, giga, 10^9} {kg, kilogramme, unit mass} {t, metric tonne, 1,000 kg}.

Contents

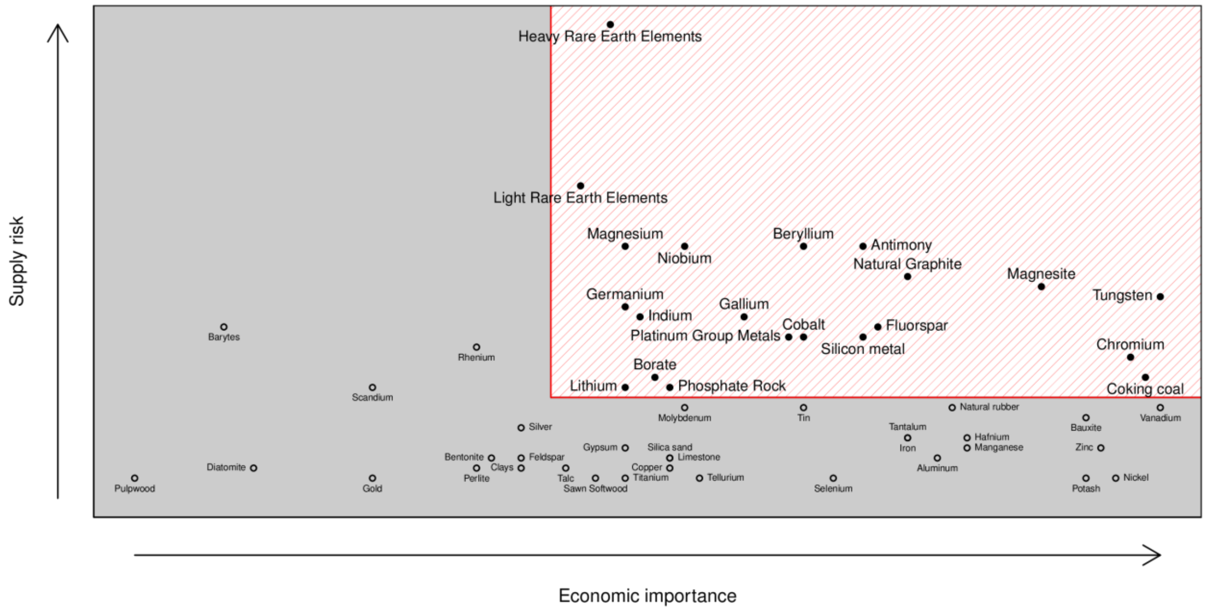
1 Executive Summary

Raw materials are fundamental to Europe's economy, and they are essential for maintaining and improving our quality of life. Recent years have seen a growth in the number of materials used across products. Securing reliable and undistorted access of certain raw materials is of growing concern within the EU and across the globe. As a consequence of these circumstances, the Raw Materials Initiative was instigated to manage responses to raw materials issues at an EU level. At the heart of this work is defining the critical raw materials for the EU's economy. These critical raw materials have a high economic importance to the EU combined with a high risk associated with their supply.

The first criticality analysis for raw materials was published in 2010 by the Ad-Hoc Working Group on Defining Critical Raw Materials. Fourteen critical raw materials were identified from a candidate list of forty-one non-energy, non-food materials. The group highlighted the need to revise this list at regular intervals. This present study follows on from this recommendation, revising and extending the work carried out previously at the EU level. Three key areas are addressed:

- Revision of the list of critical materials for the EU.
- Discussion of additional influences on raw material criticality.
- Extension of the analysis to biotic materials.

Fifty-four non-energy, non-food materials are analysed using the same methodology as the previous study; this extended candidate list includes seven new abiotic materials and three biotic materials. In addition, greater detail is provided for the rare earth elements by splitting them into 'heavy' and 'light' categories. Critical raw materials experience a combination of high economic importance and high supply risk relative to the other candidate materials, and are defined using thresholds for each measure set during the previous study. The overall results of the 2013 criticality assessment are shown below; the critical raw materials are highlighted in the red shaded area of the graph.

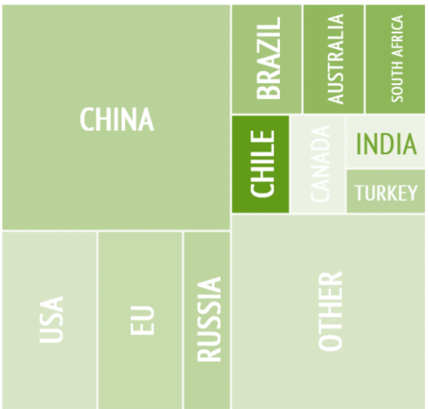


Twenty one critical raw materials are assessed as critical from the list of fifty-four candidate materials:

Antimony	**Beryllium**	**Borates**	**Chromium**	**Cobalt**	**Coking coal**	**Fluorspar**
Gallium	**Germanium**	**Indium**	**Lithium**	**Magnesite**	**Magnesium**	**Natural Graphite**
Niobium	**PGMs**	**Phosphate Rock**	**REEs (Heavy)**	**REEs (Light)**	**Silicon Metal**	**Tungsten**

This 2013 list includes thirteen of the fourteen materials identified in the previous study, with only tantalum moving out of the EU critical material list. Seven new materials are included: borates, chromium, coking coal, lithium, magnesite, phosphate rock and silicon metal. Three of these are entirely new to the study. None of the biotic materials were classified as critical. Whilst this analysis highlights the criticality of certain materials from the EU perspective, limitations and uncertainties with data, and the study's scope should be taken into consideration when discussing this list. In addition, information for each of the candidate materials is provided by individual material profiles, found in two separate documents. Further analysis is provided for the critical raw materials within these profiles.

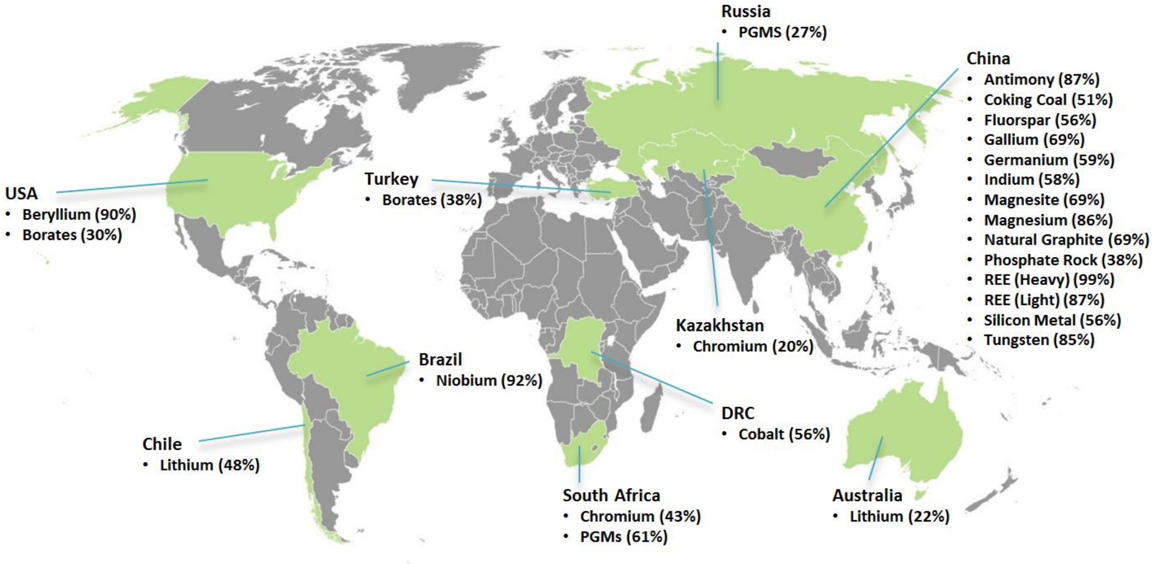
Analysis of the global primary supply of the fifty-four candidate materials identifies that 91% of global supply originated from extra-EU sources; this included most of the base, speciality and precious metals, and rubber. China is the major supplier when these materials are considered, however many other countries are important suppliers of specific materials; for instance, Russia and South Africa for platinum group metals. EU primary supply across all candidate materials is estimated at 9%. By contrast, supply of critical raw materials is more limited, with less than 3% of critical raw material supply arising from within the EU. A comparison between supply of the candidate materials and the critical materials is shown below, showing that supply becomes more concentrated for the critical materials, particularly in China.



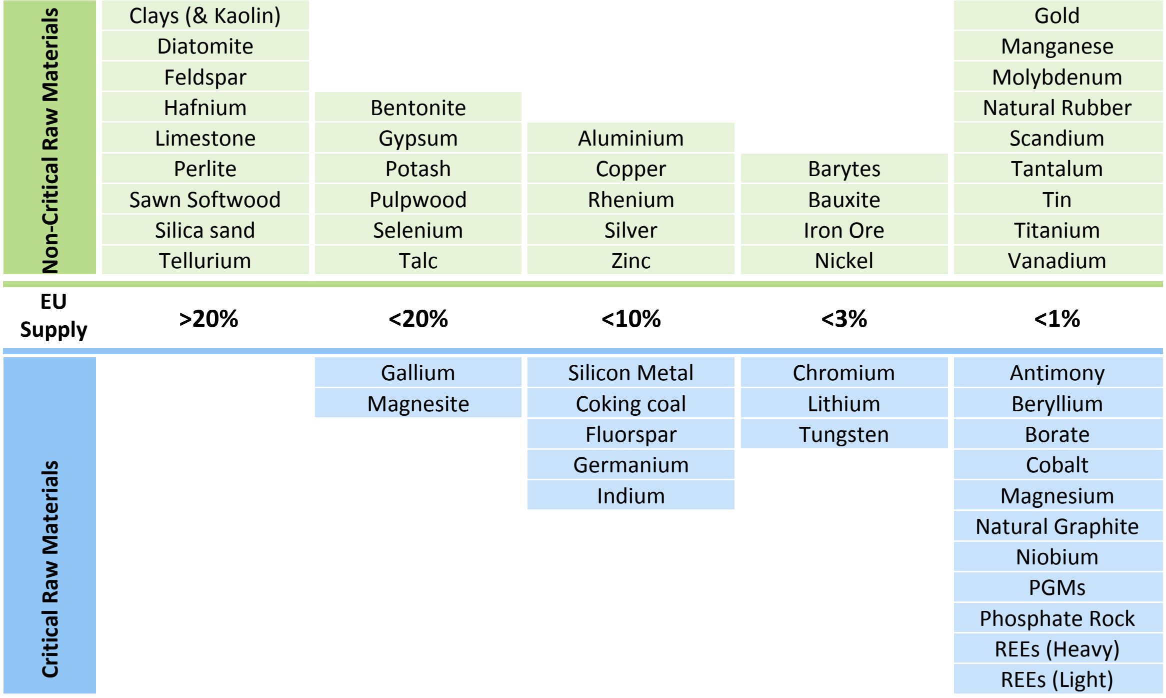
World primary supply of the 54 candidate raw materials

World primary supply of the 21 critical raw materials

The major producers of the twenty-one EU critical raw materials are shown below, with China clearly being the most influential in terms of global supply. Several other countries have dominant supplies of specific raw materials, such as the USA (beryllium) and Brazil (niobium). Supply of other materials, for example the PGMs, lithium and borates, is more diverse but is still concentrated.



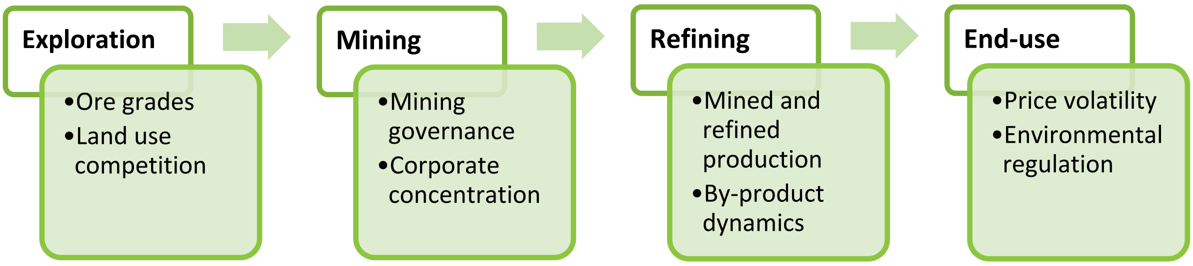
Data for primary supply highlights the difference between the EU primary supply of the non-critical raw materials and the critical raw materials.



EU Supply	**>20%**	**<20%**	**<10%**	**<3%**	**<1%**
Non-Critical Raw Materials	Clays (& Kaolin)				Gold
	Diatomite				Manganese
	Feldspar				Molybdenum
	Hafnium	Bentonite			Natural Rubber
	Limestone	Gypsum	Aluminium		Scandium
	Perlite	Potash	Copper	Barytes	Tantalum
	Sawn Softwood	Pulpwood	Rhenium	Bauxite	Tin
	Silica sand	Selenium	Silver	Iron Ore	Titanium
	Tellurium	Talc	Zinc	Nickel	Vanadium
Critical Raw Materials		Gallium	Silicon Metal	Chromium	Antimony
		Magnesite	Coking coal	Lithium	Beryllium
			Fluorspar	Tungsten	Borate
			Germanium		Cobalt
			Indium		Magnesium
					Natural Graphite
					Niobium
					PGMs
					Phosphate Rock
					REEs (Heavy)
					REEs (Light)

EU primary supply is largest for industrial minerals, wood and a small number of speciality metals, with greater than 20% production. The largest EU supply for the critical raw materials is seen for magnesite and gallium (refining), with several others between 10% and 20%. Twenty of the materials assessed in this study have less than 1% supply arising in the EU; eleven of these are critical raw materials.

In addition to the factors considered for supply risk and economic importance, eight possible influences to criticality have been discussed to add greater richness to discussions, and to propose refinements to the EU methodology. These influences are broadly linked to the stage of the raw material supply chain:



Of these possible influences, corporate concentration, mined and refined production, and price volatility provide additional quantitative assessments which allow further comparison across raw materials. The remaining five influences were found to provide additional detail and insights to discussions and recommendations within this study. For instance, land use and mining governance provide useful guidance over developing supply of raw materials.

A criticality analysis for biotic materials has been conducted for the first time in this study, to allow comparison with abiotic materials. Natural rubber, pulpwood and soft sawnwood are included as exemplar materials. The criticality methodology was found to be applicable to these materials due to its high level considerations of economic importance and supply risks, though issues with categorisation of materials and data availability made the analysis a complex task. Overall, no biotic materials were found to be critical using the same methodology and thresholds. However, future analyses could include a wider range of biotic materials to allow further comparison across a broader range of materials.

Proposed actions made by the project team include:

- The revised list of twenty-one critical raw materials for the EU should supersede the existing list of fourteen materials, and be used in place where practicable. Dissemination guidance should indicate that non-critical raw materials should not be disregarded from resulting actions.
- The results of this study should link with going EC initiatives related to raw materials and wider EU policy such as the flagship initiatives of the Europe 2020 Strategy 'an Industrial Policy for the Globalization Era', 'Innovation Union' and 'Resource Efficient Europe'.
- Dialogues with other DGs that have on-going work related to raw materials should be maintained (e.g. DG Environment, DG Trade, DG Research, JRC Institute for Energy and Transport, JRC Institute for the Environmental and Sustainability), as well as with Member States, and industry organisations.
- It is recommended that the EU list of critical raw materials continues to be updated regularly with the support of the Ad-Hoc Working Group. The scope of materials could be reviewed to ensure it remains relevant to the purpose of the exercise. Additional indicators are proposed for the quantitative methodology, these could be used in consequent studies.
- The data quality available for this work could be improved through targeted studies, particularly for recycling and end uses of materials.
- Diplomacy and dialogues with Third countries that are significant suppliers of across all materials should be maintained and expanded.
- A better environment for EU raw materials supply can be developed through the EIP and other platforms. It is recommended to establish links with the future coordination and support action under Horizon 2020 in which the concept of deposits of public importance will be explored. Improved EU raw materials governance could set a baseline for Third countries.
- Resources and reserves of critical and other raw materials in the EU and linked countries could be identified more clearly and exploitation assessed.
- The internal EU flow of critical raw materials, as well as imports and exports, could be characterised in greater detail.
- Increasing awareness of raw materials issues along supply chains and across job roles could serve to help engage industry in this topic.
- Appropriate resource efficiency and recycling actions for the critical raw materials could be identified and progressed. These could be linked to initiatives such as enabling the circular economy; for example, higher recycling rates, reducing the influence of dispersive uses, substitution and dematerialisation, remanufacturing, and re-use.
- Actions to mitigate raw materials issues could be prioritised based on accompanying improvement in environmental performance.
- A critical raw materials or by-products group within the International Study Groups could be formed.
- Issues over trade restrictions and their impact at relevant should continue to be pursued in international fora.
- Linkages between stewardship/traceability and material criticality activities could be exploited through the EITI, voluntary certification schemes, mining governance indices and sustainable management schemes for forests.
- Users of (critical) raw materials could be engaged through industry groups to develop action plans; for example, end-user investment or joint ventures for developing primary supply or refining. The involvement of SMEs should be a requirement of this action.
- Improving the availability of detailed trade statistics for the raw materials could be discussed with Eurostat, as data on individual materials are not always available.
- An application-based supply chain analysis could be conducted, taking into account other risks such as processing, manufacturing, and corporate concentration for each stage, to identify how raw materials risks compare with other risks along the supply chain.

2 Introduction

2.1 Concerns over Raw Materials

Raw materials are fundamental to Europe's economy, and they are essential for maintaining and improving our quality of life. While the importance of energy materials such as oil and gas has often been highlighted, historically the indispensable role of metals, minerals, and biotic materials has been of lower profile. However, more recently securing reliable and undistorted access to crucial non-energy raw materials has been of growing concern in economies such as the EU, US and Japan. Responses have been commenced in different nations, economic areas and companies, with the European Commission launching the "Raw Materials Initiative (RMI) - meeting our critical needs for growth and jobs in Europe" in 2008 to manage raw materials issues at an EU level.[a] The original inception of the RMI stemmed from concerns over a combination of several complex factors linked to the importance of raw materials and changing supply conditions.

Irreplaceable role in industry and society
Non-energy raw materials are intrinsically linked to all industries across all supply chain stages, and consequently they are essential for our way of life – everything is made from materials. Sectors may rely on these materials as direct inputs, for instance metals refining relies on metals ores as well as a plethora industrial minerals for production. This primary industry underpins downstream sectors, which utilise processed materials in their products and services. For example, the healthcare sector uses equipment containing high performance magnets made from rare earth elements, electricity distribution relies on pylons and cables constructed of aluminium and copper respectively, and most vehicles are equipped with tyres which are comprised of natural rubber. As a society we rely on the availability of these goods to maintain our quality of life.

Further to established applications, future technological progress and increasing quality of life are also reliant on access to a growing number of raw materials. The rapid development of hi-tech goods over recent decades has led to shifts in demand patterns for raw materials. The growth in use of flat panel televisions and touch screens is reliant on supply the indium used in transparent conducting layers; previously this metal only found niche uses. The complexity and sophistication of these products is growing, leading to a corresponding increase in the number of materials used in their production; the number of materials used in printed circuit boards has grown from a handful to sixty over the last three decades. This is coupled with increasing product complexity, for example a modern mobile phone may contain 500 to 1,000 different components.[b] The same is true of countless other products. These changing needs have further highlighted the reliance on a wider group of raw materials.

Improving environmental performance is also closely linked to raw materials, both at present and in the future. Exhaust emissions from internal combustion engines are managed through catalytic converters containing platinum group metals; no other option is viable at present. Low carbon technologies also require that the correct resources are available. Many wind turbines designs use magnets containing rare earth elements, and solar panels rely on metals such as silicon, tellurium and indium amongst others. Similar cases are seen for electric vehicles and energy efficient lighting.[c]

Only a few examples are provided above, however, it is apparent that if the quality and way of life within the EU Member States is to be maintained and improved, continued access to non-energy raw materials is essential.

---

[a] EC COM(2008) 0699 The raw materials initiative — meeting our critical needs for growth and jobs in Europe
[b] OECD Global Forum on Environment(2010), Critical Metals and Mobile Devices
[c] EU JRC (2011), Assessing metals as Supply Chain Bottlenecks in Priority Energy Technologies

EU resource dependence and concentration of supply

As a whole, Europe is highly dependent on non-energy raw materials to sustain businesses and the economy. It has been estimated that 30 million jobs in the EU are directly reliant on access to raw materials.[a] However, very little primary production occurs within Member States themselves, with the majority produced and supplied from Third countries. Primary supply figures for the fifty four materials assessed in his study show that supply is dominated by non-EU countries, with no EU28 countries in the top ten producers (Table 1). The total EU28 contribution to overall materials supply can be estimated at 9%, with France, Germany and Italy ranked the highest individually, largely due to industrial mineral production.[b]

Table 1: Countries supplying raw materials to the global market

Country	Materials Produced*	Total % of supply	Country	Materials Produced*	Total % of supply
China	48	30%	**South Africa**	26	3.9%
USA	36	10%	**Chile**	18	3.4%
Russia	42	4.9%	**Canada**	30	3.2%
Brazil	36	4.6%	**India**	30	2.5%
Australia	34	4.0%	**Turkey**	25	2.1%

** Supply data from the 54 materials assessed in this study, sources in Annex C*

In terms of materials, perlite (37%) and several other industrial minerals have the largest supply from within the EU, with hafnium refining (47%) also being important. By contrast there is no significant production of materials such as borates, indium, rare earths, and titanium within the EU, with many others produced in small quantities.[c] The EU has many and uncharacterised deposits; however, the existing economic and regulative climate, combined with growing land use competition limits the exploitation.[d] Secondary supplies can reduce the demand for primary materials. However, for many materials very little recycling and recovery occurs, and for the others it cannot completely replace primary supply even though recycling rates are high.[e] Therefore much of Europe's industry and economy is reliant on international markets to provide access to crucial raw materials.

As well as this dependence on extra-EU supply, the production of many materials is reliant on a few countries. This concentration of supply also poses concern as countries dominate supply of individual or several materials: Brazil (niobium), USA (beryllium), South Africa (platinum) and China (rare earth elements, antimony, magnesium, and tungsten). Supply concentration has often been coupled with growing competition for materials from emerging economies, and proliferation of both economic and resource nationalism. This is a reflection of many factors, such as growing economies in developing countries and evolving materials' markets. These have contributed to a restriction in supply from some of Europe and the World's most important suppliers, increasing risk across supply chains. The consequent rises in the prices and price volatility of raw materials are of continuing concern to EU Member States, as this reduces the competitiveness of manufacturing compared with other economies. This clearly has a knock-on effect across industry.

When a material experiences an acute combination of these supply concerns combined with a high economic importance they are regarded as critical.

---

[a] EC COM(2011) 0025 Tackling the Challenges in Commodity Markets and on Raw Materials
[b] Data sources are summarised in Annex E
[c] Some production occurs within the European Economic Area, such titanium production in Norway
[d] EU DG ENTR (2010) Improving framework conditions for extracting minerals for the EU
[e] UNEP (2010), Recycling of metals – A status report

2.1.2 EU Raw Materials Initiative

In order to address the complex and interrelated challenges described above, the European Commission launched an integrated strategy in 2008: the EU Raw Materials Initiative (RMI). This is the major European Union strategy relating to raw materials. The RMI has been developed based on three pillars:

1. Ensuring a level playing field in access to resources in third countries
2. Fostering sustainable supply of raw materials from European sources
3. Boosting resource efficiency and promoting recycling.

The original RMI communication has now been followed up further communications on “tackling the challenges in commodity markets and on raw materials” in 2011[a], and reporting on the progress of the RMI in 2013.[b] As a whole this work is part of the Europe 2020 strategy to ensure smart, sustainable and inclusive growth and is closely linked to the flagship initiative for a resource efficient Europe.[c]

The work programme of the RMI to date has included raw materials diplomacy, trade and development, research and innovation, sustainable EU supply, resource efficiency and recycling, as well as assessment of critical raw materials.[d] Various research projects are underway within the EU, spanning many topics including exploration, substitution of critical raw materials, co-ordination of activities in Member States, European Technology Platforms on Sustainable Mineral Resources and generation of new skills in the area of raw materials. The identification of critical raw materials for the EU’s economy sits at the heart of this work. It is worth noting that in addition to work at the EU level, many of the Member States also have their own policies in the area of natural resources; some of these are identified below.

European Innovation Partnership on Raw Materials

In addition to specific pieces of research, the Commission’s DG Enterprise and DG Industry have, with a view to increasing the availability of raw materials for European industry, launched a European Innovation Partnership on Raw Materials (EIP).[e] Its aim is to speed up breakthrough innovation across the entire raw materials value chain, and reduce the EU's import dependency on materials that are critical to the EU’s industry. This will be achieved by providing Europe with flexibility and alternatives in the supply for important raw materials, whilst taking into account the importance of mitigating negative environmental impacts of some materials during their life cycle. In doing so, Europe will become a world leader in capabilities related to exploration, extraction, processing, recycling and substitution by 2020.

The over-arching policy goals for innovation are set within the Europe 2020 Innovation Union initiative and for resource efficiency within the Europe 2020 Resource Efficient Europe initiative. The Innovation Union initiative stresses that perhaps one of the largest challenges for the EU and its Member States in the coming decade is to adopt a more strategic approach to innovation. However, the need for greater innovation in the raw material supply chain within the EU is driven by:

- a need to increase innovative activity to levels equivalent to, or levels beyond those of, the EU’s international competitors
- the need for greater security of supply within the EU caused by increasing import dependence and the potential for restriction of supply or lack of fair access that puts Europe’s industries at a competitive disadvantage
- the need for greater resource efficiency that, it is hoped, will improve material security, reduce environmental impact and improve competitive positioning.

Five areas of focus feature in the EIP on Raw Materials work programme, covering technological and non-technological policy, as well as international co-operation. Resulting actions are designed to be challenge driven, act across the whole research and innovation chain, as well as streamline, simplify, and better

---

[a] EC COM(2011) 0025 Tackling the Challenges in Commodity Markets and on Raw Materials
[b] EC COM(2013) 0442 On the implementation of the Raw Materials Initiative
[c] EC COM(2010) 2020 "Europe 2020", and COM(2011) 21 "A resource-efficient Europe: flagship initiative under the Europe 2020 strategy".
[d] http://ec.europa.eu/enterprise/policies/raw-materials/index_en.htm
[e] http://ec.europa.eu/enterprise/policies/raw-materials/innovation-partnership/index_en.htm

coordinate existing innovative activities and innovation policy instruments. They include supply measures, such as innovation funding, and also demand measures, such as labelling, standards and market led initiatives. The EIP on raw materials is on-going, with the EIP's Strategic Implementation Plan, outlining the high level targets, actions and aims to 2020 being adopted in September 2013.[a]

2.1.3 Other related initiatives

A number of initiatives relating to raw material supply have arisen within the EU, Member States and Third Countries, highlighting a growing awareness. Some examples are described in brief below.

European Commission initiatives

There are many European Commission and European Parliament initiatives that are noteworthy, and have linkages or connections to the RMI and other policy areas. Several DGs have addressed raw materials issues directly, these include:

- DG Enterprise and Industry: DG ENTR is responsible for managing the RMI. In addition to this work other units have highlighted raw materials issues, for instance in a recent communication on the Defence and Security Sector.[b] In addition in 2012 an EU-US expert workshop on Raw Material Flows and Data was held to explore raw material data inventories and data collection, and an EU-Africa Partnership Conference to address development in Africa.[c]
- DG Research and Innovation. Several FP7 grants have focused on the area of critical raw materials, with grants made available the development of new mineral processing and production technologies, particularly focussing on critical raw materials. More recently, funding has also been allocated for an EU intelligence network on raw material supply, as well the substitution of critical raw materials. In addition to funding, a series of EU/US/Japan Trilateral Workshops have been held to provide a forum to discuss policy and technical issues; the most recent of these was held in Brussels in May 2013.[d]
- The Joint Research Centre has taken a keen interest in many aspects of raw materials supply issues:
  - The Institute for Energy and Transport launched Strategic Energy Technology Plan Materials Roadmap on Enabling Low Carbon Energy, which addressed the technology agenda of the plan by proposing a comprehensive European programme on materials research and innovation enabling low carbon energy technologies for the next 10 years.[e] This is supported by two studies which provide an in depth analysis of the present state of supply and demand in the market for energy technology-related materials. They highlight the need for further research activities to support the development of new energy technologies before the 2020 and the 2050 market horizons.[f]
  - The Institute for Environment and Sustainability have published a study with input from an expert workshop discussing security of supply and scarcity of raw materials.[g] This work investigates a methodological framework for supply chain sustainability assessment within the framework of LC impact assessments and criticality assessment methodologies.
- DG Environment: Resource efficiency has been identified as a key policy by the European Union as part of the Europe 2020 strategy to smart, sustainable and inclusive growth, forming one of the seven flagship initiatives of the European Commission. Although the focus of the research relates to environmental protection, some projects relating critical raw materials are underway, mostly under the guises of waste recycling, although other key areas include alternative materials, batteries, clean technology, electric vehicles, electronic material and renewable energy (due to the critical raw materials contained in these products). Funding of projects through the EPOW scheme has also sought to identify recovery options for critical raw materials in end of life products.[h]

---

[a] http://ec.europa.eu/enterprise/policies/raw-materials/innovation-partnership/index_en.htm

[b] EC COM(2013) 0542 Towards a More Competitive and Efficient Defence and Security Sector

[c] http://ec.europa.eu/enterprise/policies/raw-materials/international-aspects/africa-conference/index_en.htm

[d] http://ec.europa.eu/research/industrial_technologies/event-13_en.html

[e] EC SEC(2011) 1609 Materials Roadmap Enabling Low Carbon Energy Technologies

[f] EC JRC (2010 & 2013) Assessing metals as Supply Chain Bottlenecks in Priority Energy Technologies & Critical Metals in the Path towards the decarbonisation of the EU Energy Sector

[g] http://lct.jrc.ec.europa.eu/assessment/assessment/ResourceSecurity-SecuritySupply

[h] EPOW (2011) Study into the feasibility of protecting and recovering critical raw materials through infrastructure development in the south east of England.

European Parliament

The European Parliament is also active in the raw materials area, with a cross-party group of MEPs for raw materials forming in 2011, and a series of reports discussing issues around raw materials supply.[a]

Member States

In addition to European level initiatives, many of the individual Member States have produced studies and policy in the area of raw materials. These may identify which materials are important to their economies, identify actions to secure long term supply of raw materials or place issues within the wider context of resource efficiency. As such the results, conclusions and outcomes from these will vary from the European study. The following is a snapshot from selected countries:

- French Strategic Metals Plan (2010) identifies areas where France is vulnerable to shortage of critical materials/metals and suggests options for the French Government to take concrete measures to secure future supply of critical materials.
- Finland's Minerals Strategy (2010) outlines a strategy for Finland to exploit known and potential mineral resources to 2050. This aims to ensure that Finland's domestic mineral sector remains dynamic and globally competitive, as well as ensuring access to minerals for Finish industry, particularly materials identified as critical.
- German Government's Raw Materials Strategy (2010) aims to support German industry in securing the raw materials that are essential for their business activities, though it will not extend to taking an active role in securing these raw materials. Instead support takes the form of instruments on raw materials policy, support for research, as well as Germany's international raw materials policy being pro-German industry.
- Dutch Policy on Raw Materials (2011) outlines three key aims: to secure availability and improve sustainability of raw materials, to restrict/reduce demand national demand for raw materials and to improve the efficiency and sustainability of raw materials consumption with the Dutch economy.
- United Kingdom's Resource Security Action Plan (2012) is a joint strategy on natural resources. It details how the UK Government recognises these issues, provides a framework for business action to address resource risks, and sets out a plan-of-action to build on the existing partnership between Government and business on natural resource concerns. The Resource Security Action Plan was accompanied by a review of national resource strategies and research activities.

International initiatives

Materials security and materials criticality has also been of growing interest internationally, leading to a number of studies and initiatives relating to raw material supply and criticality. Several countries, including both suppliers and users of raw materials have instigated studies and initiatives to develop national strategies for securing a stable supply of raw materials, linked to the most important materials for their economy (Table 2). The goals, responses and relevant materials to the responses are highlighted from this US Department of Energy review.

Whilst this analysis focuses on R&D responses, it highlights the different stages of the supply chain where countries are placed and consequently the different approaches taken. For example Japan is focusing heavily on substitution, China, on processing and metallurgy, South Korea on recycling, Australia in sustainable mining and Canada in exploration. Funding for some of these programmes can often be vast, for example South Korea is investing $300m over 10 years for its research into forty technologies covering refining, smelting, processing, recycling and substitution. Other strategies have also been adopted. Russia is also known to have an active programme on materials stockpiles and export restrictions, China has tightened the export quotas for rare earth elements ostensibly to secure internal supply, and the US has long had a stockpile for strategic defence materials.

---

[a] For examples see: European Parliament Report (2011), Report on an effective raw materials strategy for Europe & STOA(2012), Study on Future Metal Demand from Photovoltaic Cells and Wind Turbines

In the broader context of raw materials supply concerns are also being raised over the origin and responsible sourcing of raw materials, leading to renewed concerns over supply for various materials such as cobalt and gold. Materials stewardship schemes and legislation have been put in place to provide greater confidence and traceability in various materials markets, for example, schemes such as the Extractive Industries Transparency Initiative (EITI) and the International Council on Mining and Metals" Materials Stewardship Scheme. Within the US the Dodd-Frank Wall Street Reform and Consumer Protection Act requires electronics companies to verify and disclose their sources of cassiterite (tin ore), wolframite (tungsten ore), and tantalum, as part of wider legislative reforms. This was in direct response to concerns over conflict minerals arising from the Democratic Republic of the Congo and neighbouring states. Similar regulation is now under consideration in the EU.

Table 2: Materials Research and Development Policies of selected non-EU countries

Nation	Goal	Key materials identified for action	R&D Policy
Japan	Secure a stable supply of raw materials for Japanese industries	Cobalt, Nickel, Manganese, Molybdenum, REE, Tungsten, Vanadium	• Substitution research funded through METI & MEXT • Exploration, excavation, refining and safety research funded through JOGMEC
China	Maintain a stable supply of raw materials for domestic use through industry consolidation, mitigating overproduction & reducing illegal trade	Antimony, Tin, Tungsten, Iron, Mercury, Aluminium, Zinc, Vanadium, Molybdenum, REEs	• Rare earth separation techniques & exploration of new functional materials • Rare earths: metallurgy; optical, electrical, magnetic properties; basic chemical sciences
South Korea	Ensure a reliable supply of materials critical to Korean mainstay industries	Arsenic, Titanium, Cobalt, Indium, Molybdenum, Manganese, Tantalum, Gallium, Vanadium, Tungsten, Lithium, REEs	• Recycling end-use products • Designing for recyclability • Substitute materials • Production efficiency
Australia	Maintain investment in the mining industry & fairly taxing the depletion of national resources	Tantalum, Molybdenum, Vanadium, Lithium REEs	• Promote sustainable development practices in mining
Canada	Promote sustainable development & use of resources, protect the environment & public health, ensure attractive investment climate	Aluminium, Silver, Gold, Iron, Nickel, Copper, Lead, Molybdenum.	• Provide comprehensive geosciences information and infrastructure • Promote technological innovation in mining processes • Value-added mineral & metal products

Source: Adapted from US Department of Energy (2010), Critical Materials Strategy

2.2 Materials Criticality and Previous EU Study

2.2.1 Criticality in context

Materials security issues have been of growing interest to researchers, governments and other organisations alike due to increasing concerns over access to raw materials and the impact supply shortages may have. A central part of many initiatives identified above and elsewhere is to assess which materials are most "critical", allowing the most appropriate actions to be identified and taken. As a result a variety of criticality assessments have been published, each seeking to evaluate the criticality of a group of materials in relation to each other.

These studies may consider materials in different contexts:

- A specific economic zone or country, such as the EU study
- A technology focus, such as the work by the EU's JRC[a] or the US Department of Energy[b] on low carbon energy technologies, or sectors such as ICT and defence.[c]
- A company, such as analysis performed by General Electric[d]
- A more general view of supply risks or criticality for raw materials, often taking into account a longer term view.[e,f]

In addition, assessments may evaluate different set of materials chosen for context and use different criticality measures and methodologies. Whilst the aims and scopes of these analyses do vary, they all apply a selection of indicators to a group of materials to identify a list of critical materials, often combining a measure of supply risk against one of relative importance. A review of different assessments and approaches is provided in Annex F.

2.2.2 Critical raw materials for the EU

The report **Raw Materials: Study on Critical Raw Materials at EU Level**[g] study by the European Commission in 2010, an output of the Ad-hoc Working Group on critical raw materials (AHWG) is amongst the most high profile of these studies. It was prompted by the highlighted concerns over securing reliable and undistorted access to non-energy raw materials, and the detrimental impact on the wider European economy to which supply issues may lead. To identify which raw materials can be considered critical to the EU, a methodology for assessing raw materials was developed by the AHWG, assessing economic importance to the EU against supply risk, (political and environmental).[h] This methodology was devised to allow assessment of a diverse range of raw materials important to the EU's economy, allowing a pragmatic approach to the assessment of criticality that was broadly applicable. From an original list of forty one non-energy raw materials in scope, fourteen were identified as critical to the EU (Table 3).

Table 3: The 14 critical raw materials identified in the 2010 study:

Antimony	**Beryllium**	**Cobalt**	**Fluorspar**
Gallium	**Germanium**	**Graphite**	**Indium**
Magnesium	**Niobium**	**PGMs**	**REEs**
Tantalum	**Tungsten**		

However it is important to highlight that whilst these fourteen materials were identified as critical, concerns associated with other materials are also discussed by this work. As part of this study the AHWG recommended that this work was revised at regular intervals to ensure that it remained relevant and up to date, including revision of the criticality assessment. Therefore the aim of this present study is present the findings of this revision for 2013.

2.3 *Purpose of this Study*

The purpose of this present study is to revise and extend the work carried out in the previous study, taking into consideration feedback gathered from the previous exercise, and in doing so produce an

---

[a] EC JRC (2010 & 2013) Assessing metals as Supply Chain Bottlenecks in Priority Energy Technologies & Critical Metals in the Path towards the decarbonisation of the EU Energy Sector

[b] US Department of Energy (2011), Critical Materials Strategy

[c] Annex I contains a brief discussion of these sectors from the EU perspective. These summaries highlight several raw materials, with those commonly identified across sectors including REEs (particularly dysprosium, erbium, neodymium, yttrium), indium and gallium.

[d] General Electric (2010), Research Priorities for More Efficient Use of Critical Materials from a U.S. Corporate Perspective

[e] Rosenau-Tornow *et al,* Resources Policy (2009), Assessing the long-term supply risks for mineral raw materials—a combined evaluation of past and future trends

[f] Graedel *et al*, Environmental Science & Technology (2011), Methodology of Metal Criticality Determination

[g] EC (2010), Critical Raw Materials at EU Level

h An overview of this methodology is provided in Section 4 and Annex B updated list of critical raw materials for the EU. The majority of comments gathered following the previous study were positive, acknowledging the importance of the exercise, and accepting the pragmatic approach to compare such a diverse range of materials.[a]

As a response to these comments the following have been included within this study:

- Analysis of a wider range of abiotic raw materials, and disaggregated discussion on REE and PGMs
- Extension of the assessment to a selection of biotic raw materials[b]
- Wider and more detailed analysis of the critical raw materials, including further consideration of supply chain risks and issues, and forward looking trends and forecasts for supply and demand
- Discussion of other influences on criticality, such as pricing, land use, by-production, and company concentration
- Discussion of additional factors influencing biotic materials, such as biological threats
- Recommendations on approaches to improve the quantitative methodology
- Use of higher quality data and greater transparency in the assessment.

However, it should be noted that from the outset the intention of this study was to repeat the criticality analysis using the same methodology as the previous study to ensure comparability between lists.

2.3.1 Structure of report

To allow readers to focus on the most relevant parts of this work, the key areas are divided into separate sections of the report below:

- *Section 3: Scope of materials*: An outline of the materials in scope for this study including new abiotic and biotic materials, and separation of groups.
- *Section 4: Criticality analysis of raw materials*: An updated criticality analysis of the materials in scope, including biotic materials, using the same methodology to identify the critical materials.
- *Section 5: Influences to criticality*: several factors which could influence criticality have been identified, which include:
    - ore grades
    - land use competition
    - mining governance
    - corporate concentration
    - mined and refined production
    - by-product dynamics
    - price volatility
    - environmental regulation.

  Each of these is discussed in the context of materials criticality, with some consideration to methodological modifications.
- *Section 6: Criticality analysis of biotic materials*: The use of the criticality methodology for biotic materials, specifically natural rubber and wood (sawn soft wood and pulpwood) is described, and a criticality evaluation conducted. Additional influences relevant to biotic materials are discussed.
- *Section 7: Suggested Actions*

Annexes A to G contain supporting information, and additional analysis conducted in the process of this study. Annex H details proposed changes to the scope and methodology for the next study. Annex I contains sectoral specific discussions on critical materials for the defence industry and the energy technology sector.

Profiles for individual materials are provided in separate documents, one each for critical and non-critical raw materials. These short summaries contain background information, supply and demand data, a description of markets, applications, resource efficiency and recycling practices, and identification of specific issues for each material. Additional information is provided for the critical raw materials including a basic supply chain analysis, more detailed information on ore grades, by-production and processing, supply and demand forecasts, and trade data analysis.

---

[a] http://ec.europa.eu/enterprise/policies/raw-materials/public-consultation/contributions/index_en.htm

[b] Biotic materials are biologically derived materials, e.g. natural rubber. Abiotic materials refer to non-biologically derived materials, e.g. metals and minerals.

3 Materials Scoping

The scope of materials considered in this study includes fifty-four non-energy, non-food abiotic and biotic materials which have been identified as important to the EU's economy (Table 4). These materials represent a diverse group, including materials that are mined or cultivated as well as some refined materials that are considered highly important to downstream sectors.

Table 4: List of candidate materials

Aluminium	**Antimony**	**Barytes**	**Bauxite**	**Bentonite**	**Beryllium**
Borates	**Coking Coal**	**Chromium**	**Clays (and kaolin)**	**Cobalt**	**Copper**
Diatomite	**Feldspar**	**Fluorspar**	**Gallium**	**Germanium**	**Gold**
Gypsum	**Hafnium**	**Indium**	**Iron ore**	**Limestone (high grade)**	**Lithium**
Magnesite	**Magnesium**	**Manganese**	**Molybdenum**	**Natural Graphite**	**Natural Rubber**
Nickel	**Niobium**	**Perlite**	**Phosphate Rock**	**Platinum Group Metals**	**Potash**
Pulpwood	**Rare Earth Elements - Heavy**	**Rare Earth Elements - Light**	**Rhenium**	**Sawn Softwood**	**Scandium**
Selenium	**Silica Sand**	**Silicon Metal**	**Silver**	**Talc**	**Tantalum**
Tellurium	**Tin**	**Titanium**	**Tungsten**	**Vanadium**	**Zinc**

Compared with the 2010 study, in which forty one materials were analysed, new abiotic materials have been added, and biotic materials are assessed for the first time. In addition, the rare earth elements group has been split into three smaller groups. This reflects changing concerns over specific materials, as well as the desire to analyse criticality across a broader range of materials.

The materials considered are varied, with the list including industrial minerals, ores, biotic materials, and processed or refined materials. Each of these may have different grades or types, particularly for industrial minerals and wood based materials. Readers are therefore directed to the separate documents containing individual material profiles which provide a detailed description of the material assessed.[a] However, the overall approach to the assessment remains consistent with the previous study, allowing comparison of results across studies.

---

[a] For instance in the case of Clays (and Koalin), kaolin and kaolinitic clays are assessed, and Limestone (high grade) refers specifically to ground calcium carbonate.

3.1 Abiotic Materials

The abiotic materials considered includes all the forty one materials included in the 2010 study, with coking coal, gold, hafnium, potash, phosphate rock, selenium, silicon metal and tin added.

In line with the previous study, the abiotic raw materials consist of metals (or metallic ores) and industrial minerals using the following definitions:

- Metallic ore: a rock or sediment containing one or more minerals from which one or more metals can be extracted.
- Industrial mineral: mineral, which may be used in an industrial process directly due to its chemical/physical properties. Industrial minerals are used in a range of industrial applications including the manufacture of steel, chemicals, glass, fertilisers and fillers in pharmaceuticals and cosmetics, ceramics, plastics, paint, paper, and the treatment of gases and waste, etc. Industrial minerals include barites, bentonite, borates, clays, diatomite, feldspar, fluorspar, gypsum, limestone, silica sand, talc, and many others.

As before, a breakdown of certain material's value-chains is considered in order to analyse their specific supply risks. This was the case for bauxite/aluminium and magnesite/magnesium.

Two groups of materials, platinum group metals (PGMs) and rare earth elements (REEs) are included in this scope. The PGMs consist of six metals: palladium, platinum, rhodium, ruthenium, iridium and osmium. These have been grouped together for the purposes of the criticality analysis to allow comparison with the previous study. Additional information is provided for palladium, platinum and rhodium in the materials profiles to allow for a more nuanced understanding of influencing factors.

The REEs are a group of seventeen metals, which are often discussed together due to their similar properties (Table 5). In the previous study the REEs were considered as a single group. To provide greater insight in this study, and to reflect the different supply and demand issues faced by different REEs, this single group is been split into three in this analysis: light rare earth elements (LREE), heavy rare earth elements (HREE) and scandium.

Table 5: Classification of rare earth elements in EU Critical Raw Materials studies

2010 Study	2013 Study	Rare Earth Elements
Rare Earth Elements	Scandium	Scandium
	Rare Earth Elements - Light (LREE)	Lanthanum
		Cerium
		Praseodymium
		Neodymium
		Samarium
	Rare Earth Elements - Heavy (HREE)	Europium
		Gadolinium
		Terbium
		Dysprosium
		Erbium
		Yttrium
		Others (holmium, erbium, thulium, ytterbium, and lutetium)

Whilst a formal definition of which metals constitute the REEs exists,[a] different sub-divisions may be used depending on context. For the purposes of this study scandium has treated completely separated as data showed its production and applications are not strongly linked to the other REEs. The remaining sixteen metals are split and light and heavy groupings. This distinction is commonly made, however different groupings are used depending on context, for instance from a technical or from an economic assessment. Within this study the REEs have been split into LREEs and HREEs between samarium and europium. This is the approach taken by several market reporters[b] and mining companies.[c] This division is partly based on respective chemical properties and geological availability, but also upon their different sources, market values and end-markets. As with the PGMs, more detailed information is provided within the profiles for each individual metal identified in Table 5. .

3.2 *Biotic Materials*

Three biotic materials have been included in the criticality assessment:

Natural rubber	Pulpwood	Sawn Softwood

These materials have been chosen as exemplars of biotic materials to demonstrate the application of the EU criticality methodology to biotic materials, and to allow comparison with abiotic materials. A more in-depth discussion for each of these is provided in Section 6.

---

[a] Nomenclature of Inorganic Chemistry: IUPAC Recommendations (2005), International Union of Pure and Applied Chemistry.
[b] For instance Roskill and Industrial Minerals.
[c] See for instance, Tasman Metals and Avalon Rare Metals

4 Criticality Analysis

4.1 Introduction

This section presents the revised criticality analysis for all raw materials. This assessment has used the same methodology, indicators and thresholds as the original 2010 criticality assessment at EU level, but with updated data and a wider range of materials. This enables a side-by-side comparison of both assessments (2010 and 2013) to understand how the criticality of materials has changed during this time. A review of the feedback and other studies indicated that the overall approach and methodology remains appropriate for the context and aims of the study, allowing various factors influencing criticality to be captured at a broad level. The scope of materials included in this analysis has been expanded compared to 2010; this has been described in Section 3.

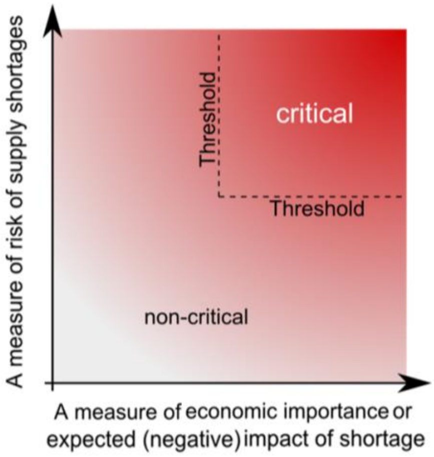
4.2 EU Criticality Methodology

The EU methodology used to assess criticality has a combination of three measures:

- Economic importance.
- Supply risk – Poor governance.
- Supply risk – Environmental country risk.

Compound indicators are used for each of these three measures; therefore each takes multiple factors into account. The result is a relative ranking of the materials across the three measures, with a material defined as critical if it exceeds the threshold for economic importance and the supply risk (Figure 1).

Figure 1: General scheme of the criticality concept projected into two dimensions.



Source: Sievers, Henrike; Buijs, Bram; Tercero Espinoza, Luis A. (2012): Limits to the critical raw materials approach. In: Proceedings of the ICE - Waste and Resource Management 165 (4), 201–208.

In this methodology the combination of the results for economic importance and each supply risk leads to two, two-dimensional depictions (one for supply risks arising from poor governance and one arising from risks due to low environmental standards). If a material is in the critical region for either of these it is defined as a critical material. In the previous study the thresholds were set at 5 for economic importance and 1 for both measures of supply risk based on a decision by the AHWG. The same thresholds are used in this study for consistency.

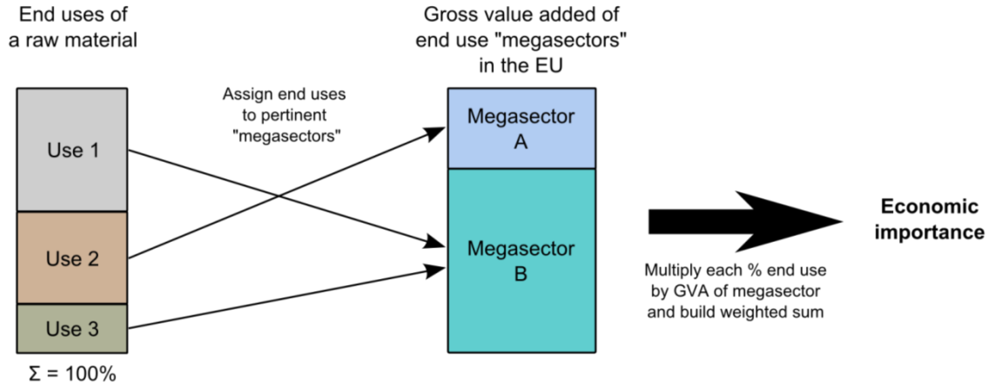
The general approach to calculating these measures for each of the materials is described below, and a complete, mathematical description of the methodology is provided in Annex B and worked examples in Annex D.

4.2.1 Economic importance

Measuring the economic importance of a raw material for an economy is a complex task, presenting not only data but also conceptual and methodological difficulties. Because of this a pragmatic approach was taken when developing the methodology, to allow the comparison of non-energy raw materials in a relative ranking.

This analysis is achieved by assessing the proportion of each material associated with industrial megasectors at an EU level (Figure 2). These proportions are then combined with the megasectors' gross value added (GVA) to the EU's GDP. This total is then scaled according to the total EU GDP to define an overall economic importance for a material.

Figure 2: Visualization of the compound indicator for economic importance. GVA = Gross value added obtained from EUROSTAT's Structural Business Statistics for the EU27.



Source: Fraunhofer ISI.

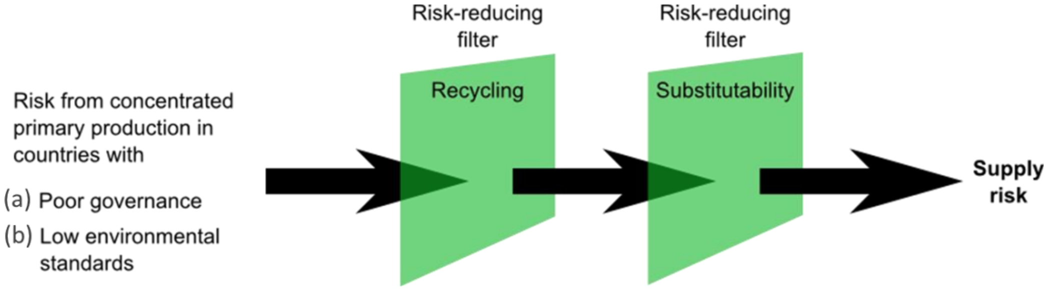
A key feature of the approach is that it is independent of both market size and price of the individual raw materials. Instead it focuses on the benefit these raw materials have for the European manufacturing economy, which can be viewed as more in line with a measure of "impact".

4.2.2 Supply risks (Poor governance and low environmental standards)

Within the methodology, a large influence on supply risk is assumed to be concentrated primary supply from countries exhibiting either poor governance (because the supply may be interrupted e.g. through political unrest), or low environmental standards (because the likelihood of large accidents leading to supply disruption is higher under such conditions). It should be noted that no direct measure of geological availability is included within this methodology due to the timescales considered.

However, this risk only applies to primary production, as if any secondary production takes place it does not depend on geology. Therefore, the supply risk is seen to be reduced by the availability of secondary supply from end-of-life products. Furthermore, the risk is reduced by the existence of options for full substitution (price and performance). The interplay of these individual elements yield a composite indicator for supply risk is graphically shown in Figure 3.

Figure 3: Visualisation of the compound indicator for supply risk as defined by Critical Raw Materials



Source: Fraunhofer ISI.

Therefore the overall supply risks are considered to arise from a combination of several factors, namely:

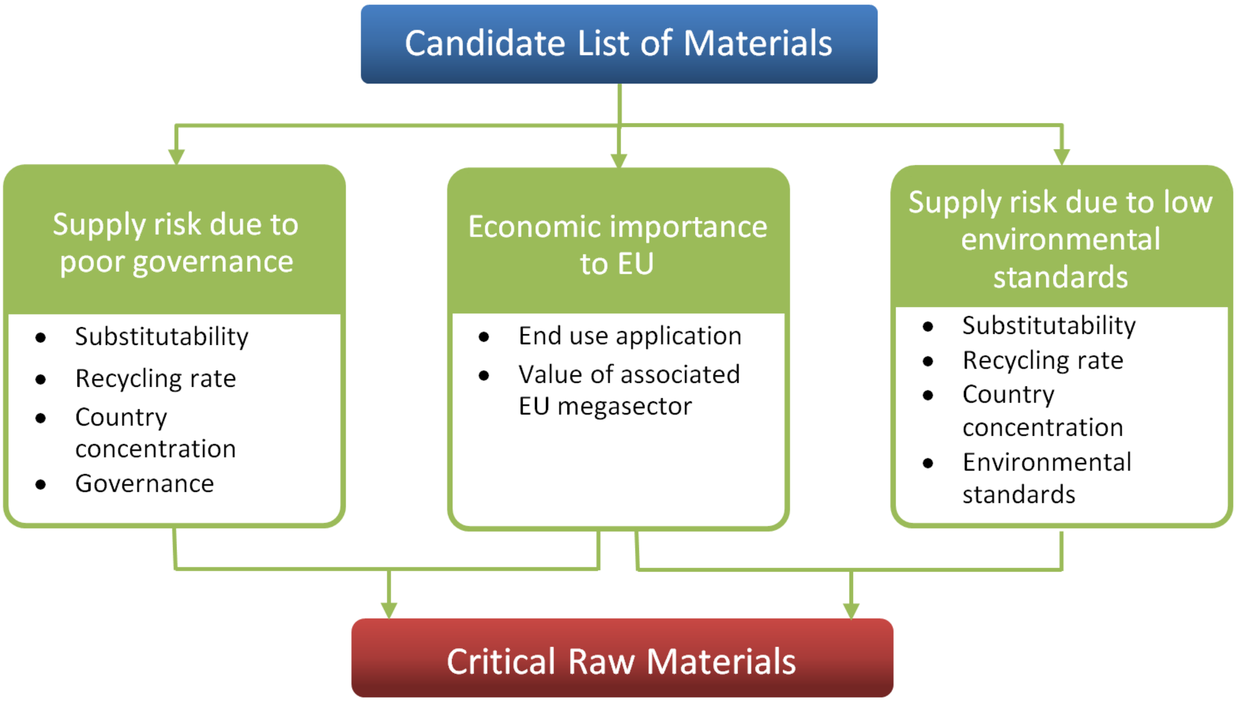
1. substitutability
2. end-of-life recycling rates
3. high concentration of producing countries with either (a) poor governance, or (b) low environmental standards.

Factors 3 and 4 are taken into account through Herfindahl-Hirschman-Index.[a] This Index has been modified to take into account country-level production with an indication of poor governance or low environmental standards. Country-level data on production is provided quantitatively from the various sources in Annex C. Poor governance and low environmental standards are indicated by the World Governance Index (WGI) and the Environmental Performance Index (EPI) respectively, both are in the public domain with values used presented in Annex C. These indices take a variety of influences into account. For example, the WGI includes voice and accountability, political stability, government effectiveness, regulatory quality, rule of law and control of corruption.

Within this methodology, increased recycling is assumed to be riskless and to reduce overall supply risk, as it can provide an alternative to primary production. This factor is included by the use of a total end-of-life recycling rate for each material. Therefore this assessment only considers recycling from old scrap in the calculation of supply risk. Substitution is assumed to influence risk in a similar way. If a raw material can be substituted, the risk to supply is lowered. To include this in the assessment, difficulty of substitution is estimated for each application of a material through expert judgment. These scores are then scaled according to the proportion of material used in the application and are then aggregated to provide an overall factor for each material.

A schematic of the overall EU criticality assessment methodology for raw materials is shown in Figure 4.

Figure 4: Schematic of EU criticality methodology



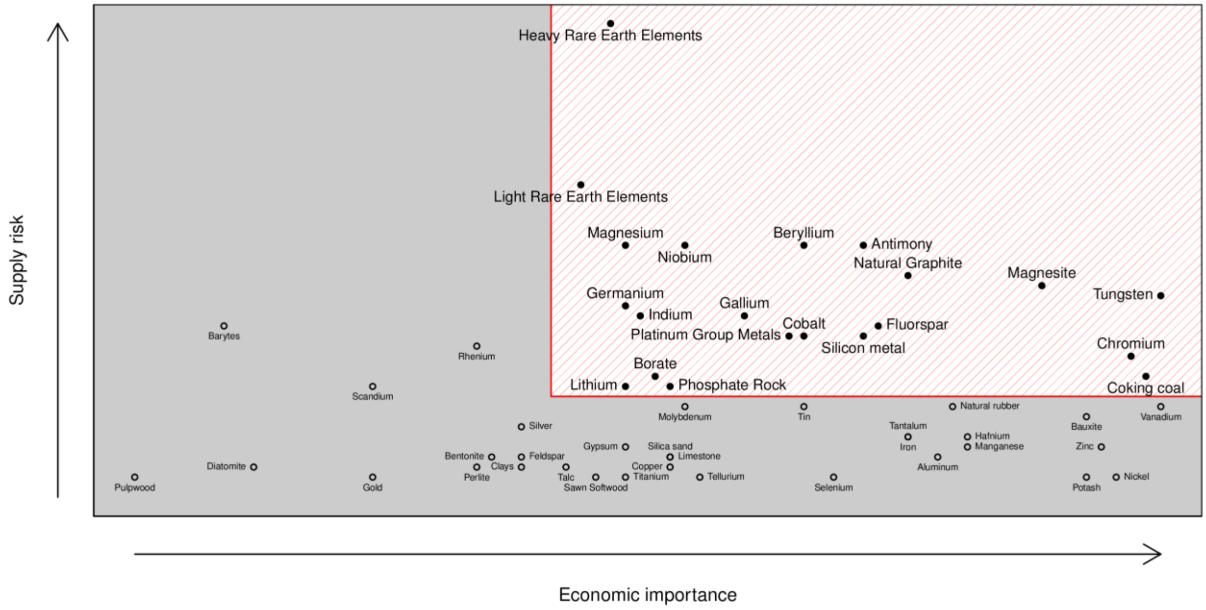
---

[a] This index is more usually used to measure the size of a company in relation to the whole industry, providing an indication of competition within a sector.

4.3 Results of Criticality Analysis

When the EU criticality methodology is applied to the list of fifty four candidate raw materials twenty one materials are classified as critical (Figure 5 & Table 6). In this assessment the highest score for either supply risk measure is used to assess criticality; however, this has little impact on the assessment as discussed below. Large format versions of this combined chart, and two comparing separate results for poor governance and low environmental standards supply risks against economic importance, are in Annex E.

Figure 5: Updated criticality assessments for the EU for 2013, using the highest value for supply risk



The same methodology and thresholds as the previous study which identified fourteen critical raw materials from a candidate list of forty one, though in the former analysis REE present as a single group rather than separated.

Table 6: EU Critical raw materials (2013)

Antimony	**Beryllium**	**Borates**	**Chromium**	**Cobalt**	**Coking coal**	**Fluorspar**
Gallium	**Germanium**	**Indium**	**Lithium**	**Magnesite**	**Magnesium**	**Natural Graphite**
Niobium	**PGMs**	**Phosphate Rock**	**REEs (Heavy)**	**REEs (Light)**	**Silicon Metal**	**Tungsten**

All of the critical raw materials are above the thresholds when both measures of supply risk are considered, with the exception of lithium. It appears as non-critical and critical for the poor governance and low environmental performance indicators respectively. This contrasts with the previous study in which the environmental performance indicator introduced no additional critical materials. This is further examined in the lithium material profiles. The analysis also shows that REEs and both light and heavy sub-groups fall into the critical region; however, none of the three biotic materials included in this analysis are considered critical using this methodology.

This new list of twenty one includes the majority of the previous fourteen minus tantalum. Seven new materials are included, four of which were included in the 2010 analysis (borates, chromium, lithium and magnesite) and three of which are new to the analysis (coking coal, phosphate rock and silicon metal). Figure 6 highlights the differences in critical raw materials between each analysis. A comparison of scores for the 2013 and 2010 study is provided in Annex E.

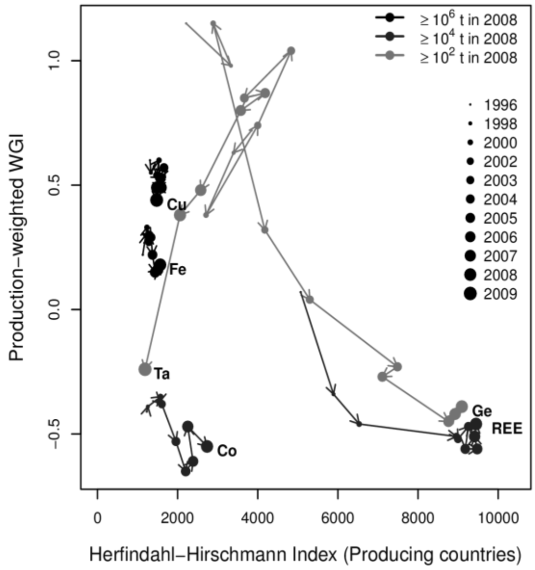
*Figure 6: Comparison of EU critical raw materials from 2010 and 2013. *denotes new material in scope*

2010 Assessment only	Common to both Assessments	2013 Assessment only
Tantalum	Antimony	Borates
	Beryllium	Chromium
	Cobalt	Coking coal*
	Fluorspar	Lithium
	Gallium	Magnesite
	Germanium	Phosphate Rock*
	Indium	Silicon Metal*
	Magnesium	
	Natural Graphite	
	Niobium	
	PGMs	
	Rare Earths (Heavy)	
	Rare Earths (Light)	
	Tungsten	

2010 Critical Raw Materials **2013 Critical Raw Materials**

Perhaps the most notable change is tantalum leaving the list of critical raw materials. This is on account of a reduced supply risk indicator, in turn resulting from changes in the concentration of tantalum primary production. Australia (with excellent governance rating) and D.R. Congo (with poor governance rating) have historically been major tantalum producers and their respective shares in world supply are known to vary strongly from year to year, depending on the price of tantalum (Figure 7). At the time of the previous exercise, Australian mines had closed down due to low tantalum prices such that D.R. Congo had a very large role in world supply. In the meantime, Brazil has emerged as an important tantalum supplier. Nevertheless, it is worth pointing out that reliable tantalum production figures for conflict regions are very difficult to obtain.

Figure 7: Changes in concentration and production-weighted World Governance Indicator (WGI) for selected metals grouped by 2008 tonnage. The values of the WGI vary modestly year to year therefore the large variations seen are due to changes in the relative (country) concentration of production.



Source: Buijs, Sievers and Tercero Espinoza (2013): Proceedings of the ICE - Waste and Resource Management, 165 (4) 201-208. http://dx.doi.org/10.1680/warm.12.00010

Borates enter the list through a modest increase in supply risk; its economic importance did not change significantly. The same applies to chromium and magnesite. This is broadly because the supplying countries have become more concentrated, rather than a change in other parameters.

Phosphate rock, coking coal and silicon are critical raw materials that are also new additions to the candidate list. In the economic importance axis, all are comfortably over the threshold. However, both coking coal and phosphate rock are very near the threshold for supply risk, due to moderately concentrated supply combined with poor substitutability and low recycling rates.

Comparison of Figure 5 with the previous analysis reveals that most raw materials have changed their relative positions. This is due to changes in one or more of the variables. On the side of economic importance, these changes are in part due to actual changes in the distribution of end uses and in part because the new data applies to a different geographical area (see Annex C). Moreover, due to changes in the value added generated in each of the megasectors, the economic importance of raw materials changes from year to year even if the distribution of end uses remains the same. Changes in megasector GVA have affected several megasectors strongly (see Annex C). The largest reductions in terms of GVA are seen for Metals which has had a reduction in GVA of €24Bn or 13%, and Electronics and ICT which has been reduced by €18bn or 15%. Megasectors showing the largest growth in GVA terms are Pharmaceuticals showing a growth of €15bn or 22% and Food growing by €11bn or 7%.

4.4 Availability and Quality of Data

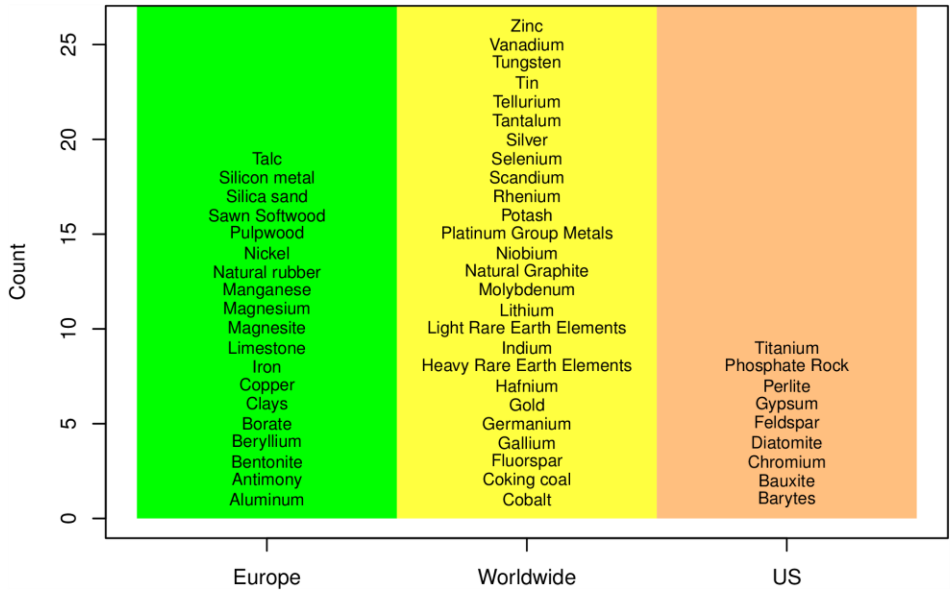
One of the key challenges in performing a large scale comparison of the criticality of raw materials is the access to pertinent data of high enough quality. Some of the issues known from the previous exercise remain. A summary of data sources for production and end use data is presented in Annex C and a summary of the supply risk and economic importance assessments is given in Annex E. Data for each material can be found in the profiles.

4.4.1 Economic importance

Distribution of end uses

The key issue here lies in the different geographical regions to which end use data apply, with data for Europe, USA and World being used as they are available. In many cases, there are no significant differences between these, but this is not a rule. Figure 8 shows the geographical distribution of end-use data, showing the majority is for Europe or worldwide. Overall data for fourteen materials is EU-based, for nine is US-based, and for the remainder is worldwide.

Figure 8: Distribution of data sources for end use data.



Value added of the megasectors

The most recent data from EUROSTAT has been used for 2010, this compares well with the data from the 2010 study which used 2006 data. However, changes to the NACE coding in this timeframe means that remapping of between the two was required (see Annex C). However, this exercise allowed good alignment between the data sets; therefore this should not influence the comparability of the two studies. Analysis of the five years 2006 to 2010 shows year to year variation between the values for each sector as would be expected.

4.4.2 Supply risk

Production data

Production data is generally available and of good quality for metals, natural rubber and for some industrial minerals. The data for some industrial minerals is of lower quality, either due to limitations with location, grades and/or market segments. Compared to the previous exercise, this assessment profits from access to data from Roskill and Raw Materials Group (licensed as the database Raw Materials Data). Nevertheless, there is no common base year for the production data. Instead, the dataset that was perceived to be of higher quality based on detail, source and processing stage was considered even if it was not the latest available, leading to a combination of years ranging from 2010 for World Mining Data up to 2012 for Raw Materials Data. Data for the biotic materials is of variable quality, and is discussed further in Section 6.

World governance Indicator

This indicator is available and considered of good quality. The issue of its applicability is discussed in a later section. The latest available data is for 2011.

Environmental performance Index

This indicator is available for all countries assessed and considered of good quality.

Recycling rates

These are available but of varying quality. The main source for abiotic materials is the UNEP report on recycling (2011), a draft of which was also used for the previous assessment. Moreover, the sources behind the UNEP report vary in quality and timeliness. Data for biotic materials is of good quality for both wood types, but poor for natural rubber with not official figure available.

Substitutability

The inherent weakness in this variable is the difficulty in assessing substitutability itself: an issue of judgement as much as of data. This will affect especially materials close to the threshold for supply risk (i.e. borates, phosphate rock, PGM, cobalt, coke, chromium, vanadium, bauxite, tin, tantalum and lithium). Notice that the substitutability used in the supply risk assessment is tied to the distribution of end uses coming from the assessment of economic importance. Therefore, the regional issues referred to above also affect this variable and might lead to a mis-specification here.

4.5 Analysis of Supply

Analysis of the primary supply data used in this study allows twenty countries to be identified which are the largest producers of biotic and abiotic materials, based on percentage contribution across the fifty four materials in scope, Table 7.[a] Figures in this table were calculated using the supply data across all fifty four raw materials. This data was aggregated using the percentage production of each material for each country for all materials as well as separately for the critical raw materials. Therefore each material contributes equally for the purposes of the analysis below.[b]

---

[a] Data from sources in Annex C, individual material data is available in the materials profiles

[b] The range of tonnages and values for the materials means that analysis using these measures would be dominated by a few materials, therefore a percentage based approach was used.

The twenty countries highlighted supply approximately 82% of the fifty four materials in scope for this study when primary production is considered. Comparison with the previous study shows that high level supply has remained relatively consistent, though changes may occur at an individual material level.

Table 7: Countries with largest contribution to primary raw material supply and critical material supply

Country	Materials supplied (Out of 54)	Overall % contribution	Critical raw materials supplied (Out of 21)	% Contribution to CRM supply
China	48	30%	19	47%
USA	36	10%	10	9%
Russia	42	5%	16	4%
Brazil	36	5%	12	6%
Australia	34	4%	11	2%
South Africa	26	4%	9	6%
Chile	18	3%	3	3%
Canada	30	3%	11	2%
India	30	3%	8	2%
Turkey	25	2%	7	2%
Japan	18	2%	2	1%
France	13	2%	1	0%
Germany	17	1%	3	1%
Indonesia	16	1%	2	0%
Kazakhstan	23	1%	7	2%
Mexico	24	1%	5	1%
Peru	17	1%	3	0%
DRC	9	1%	3	3%
Italy	11	1%	0	0%
Thailand	20	1%	4	0%

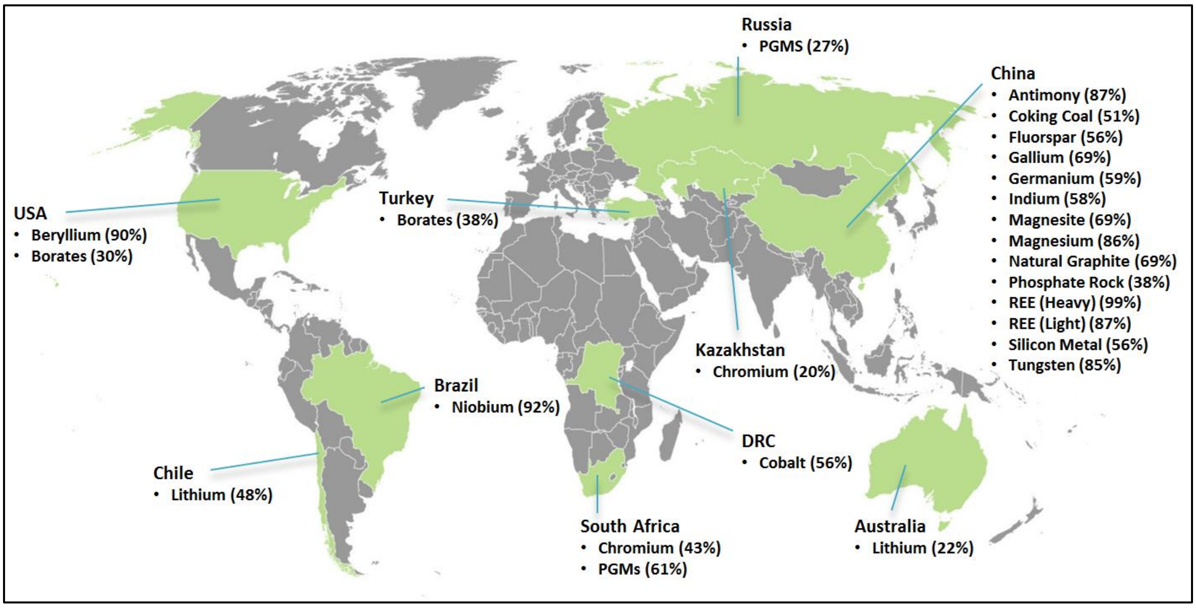
Source: Based on primary global supply figures, sources in Annex C

Table 8: Percentage of primary supply of critical raw materials from most significant producing countries

Critical raw material	% Supply	Major suppliers (>20%)	Critical raw material	% Supply	Major suppliers (>20%)
Antimony	93%	China (87%)	Magnesite	86%	China (69%)
Beryllium	99%	USA (90%)	Magnesium	96%	China (86%)
Borates	88%	Turkey (38%) USA (30%)	Natural Graphite	93%	China (69%)
Chromium	88%	South Africa (43%) Kazakhstan (20%)	Niobium	99%	Brazil (92%)
Cobalt	82%	DRC (56%)	PGMs	93%	South Africa (61%) Russia (27%)
Coking Coal	94%	China (51%)	Phosphate Rock	66%	China (38%)
Fluorspar	84%	China (56%)	REE (Heavy)	100%	China (99%)
Gallium	90%	China (69%)	REE (Light)	100%	China (87%)
Germanium	94%	China (59%)	Silicon Metal	79%	China (56%)
Indium	81%	China (58%)	Tungsten	91%	China (85%)
Lithium	83%	Chile (48%) Australia (22%)	**Total**	**90%**	**China (47%)**

These twenty countries are also the largest suppliers of the critical raw materials. Table 8 shows the contribution of these countries to the supply of the critical raw materials, with 90% of supply coming from these twenty countries. All major suppliers of the individual critical raw materials fall within this group of twenty countries. Other significant producers not in this group include Argentina (Lithium, 16%) and Morocco (Phosphate rock 15%).

Figure 9: Major supplying countries of the EU Critical Raw Materials



In terms of EU supply, around 9% of raw material supply is indigenous to the EU according to the data gathered. This is includes large supplies of hafnium (47%, linked to refining), clays (37%), perlite (37%), silica sand (35%), feldspar (35%), diatomite (28%) and sawn softwood (26%). For the critical raw materials the supply situation is more limited. Total supply across all twenty one critical raw materials can be estimated at under 3%, with over half having no or very limited production within the EU (Figure 10) . The critical raw materials with the highest production are gallium (12%), magnesite (12%), silicon metal (8%) and germanium (6%) having the highest production.

Figure 10: EU Primary production of the candidate raw materials, split by non-critical and critical

Non-Critical Raw Materials	Clays (& Kaolin)				Gold
	Diatomite				Manganese
	Feldspar				Molybdenum
	Hafnium	Bentonite			Natural Rubber
	Limestone	Gypsum	Aluminium		Scandium
	Perlite	Potash	Copper	Barytes	Tantalum
	Sawn Softwood	Pulpwood	Rhenium	Bauxite	Tin
	Silica sand	Selenium	Silver	Iron	Titanium
	Tellurium	Talc	Zinc	Nickel	Vanadium
EU Supply	**>20%**	**<20%**	**<10%**	**<3%**	**<1%**
Critical Raw Materials		Gallium	Silicon Metal	Chromium	Antimony
		Magnesite	Coking coal	Lithium	Beryllium
			Fluorspar	Tungsten	Borate
			Germanium		Cobalt
			Indium		Magnesium
					Natural Graphite
					Niobium
					PGMs
					Phosphate Rock
					REEs (Heavy)
					REEs (Light)

4.6 Outlook for the Critical Raw Materials

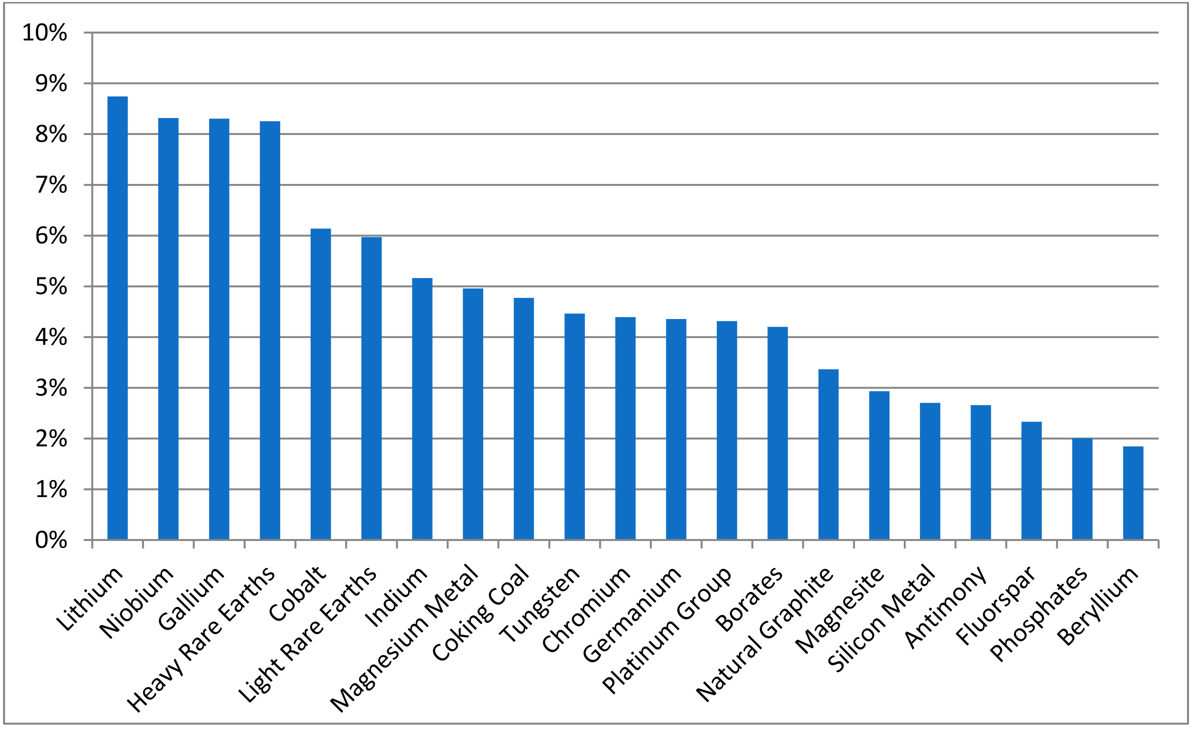
For each of the raw materials identified as critical within this report, extended analysis has been compiled to assess any additional risks or mitigating factors that may influence future policy considerations, for example developing primary supply may be appropriate for some materials but not others, similarly for secondary supply. This analysis includes supply chain analysis, some assessments of ore quality/by-product dynamics and EU trade patterns. This information is included in the profiles for the critical raw materials.

One further part of the extended analysis has been to compile long-term forecasts for the supply and demand for each of the critical raw materials. Roskill Information Services supplied a significant amount of data for this purpose, although numerous other sources of information were also reviewed for these materials to gain complete coverage. This information is reviewed here to provide a forward looking view on supply and demand for the critical raw materials.

It should be noted that a supply deficit/surplus does not necessarily imply a change in criticality of these materials. Many of the critical materials could experience a future supply surplus; however, this does not paint a complete picture of criticality. For example factors such as supply concentration, country risk, and substitutability are taken into consideration within the methodology, and supply deficit/surplus of materials is not directly measured. These forecasts extend beyond the timescales of the criticality analysis, which takes a snapshot view. Therefore this analysis is a useful tool for understanding the linked issue of current and future supply and demand and changes thereof, rather than a direct reflection of criticality.

Figure 11 summarises the demand forecasts for each of the critical raw materials. All are predicted to experience demand growth, with lithium, niobium, gallium and heavy rare earth element forecast to have the strongest rates of demand growth, exceeding 8% per year for the rest of the decade. Table 9 categorises each of the critical raw materials by their corresponding rate of demand growth forecast.

Figure 11: Forecast average demand growth to 2020 for critical raw materials (% per year)



Source: Roskill Information Services (September 2013) and other data in the extended profiles

Table 9: Forecast average demand growth to 2020 for critical raw materials (% per year)

Very Strong (>8%)	Strong (4.5%-8%)	Moderate (3%-4.5%)	Modest (<3%)
Lithium	Cobalt	Tungsten	Magnesite
Niobium	Light Rare Earths	Chromium	Silicon Metal
Gallium	Indium	Germanium	Antimony
Heavy Rare Earths	Magnesium Metal	Platinum Group Metals	Fluorspar
	Coking Coal	Borates	Phosphates
		Natural Graphite	Beryllium

Source: Roskill Information Services (September 2013) and other data presented in the extended profiles

However, the overall demand growth rates do not necessarily pose concerns in themselves, unless supply is unable to keep up with these forecast growth rates. The evolving market balance situation for each of the critical raw materials is summarised in Table 10 and Table 11. This has been colour-coded according to whether a surplus, deficit or market balance is forecast for a particular year (although for some of the critical raw materials only supply capacity forecasts are available).

The result of these supply-demand forecasts are that certain critical raw materials have been identified as having a risk of market deficit. These include antimony, coking coal, gallium, indium, platinum group metals, heavy rare earths and silicon metal (Table 10 and Table 11). These raw materials may warrant policy actions to mitigate the impact of these potential market deficits. Other critical raw materials have a significant risk of surplus, which in turn may deter further policy and investment decisions. However, care is required when interpreting these results, and readers are directed towards the material profiles for a more complete and specific understanding of the circumstances for each critical material.

Table 10: Forecast market balance for critical raw materials to 2020

Critical Raw Material	2012	2015	2020
Antimony	Small deficit	Large deficit	Large deficit
Borates	Large surplus	Large surplus	Small surplus
Chromium	Balance	Balance	Balance
Cobalt	Small surplus	Small surplus	Small surplus
Coking Coal	Small deficit	Small deficit	Balance
Fluorspar	Balance	Large surplus	Small surplus
Gallium	Large surplus	Small deficit	Large surplus
Germanium	Small surplus	Balance	Balance
Indium	Small surplus	Small deficit	Small deficit
Lithium	Large excess capacity	Large excess capacity	Large excess capacity
Magnesite	Large surplus	Small surplus	Balance
Magnesium	Large excess capacity	Large excess capacity	Large excess capacity
Natural Graphite	Small surplus	Large surplus	Large surplus
Niobium	Large excess capacity	Large excess capacity	Large excess capacity
Phosphates	Small surplus	Small surplus	Large surplus
Platinum Group Metals	Small deficit	Small deficit	Small deficit
Rare Earth Elements - Light	Large surplus	Large surplus	Large surplus
Rare Earth Elements - Heavy	Large deficit	Balance	Small deficit
Silicon Metal	Small deficit	Balance	Balance
Tungsten	Balance	Small surplus	Balance

Key:	Balance: +/- 1%	Small <10%	Large: >10%

Source: Roskill Information Services (September 2013) and other data in the extended profiles

Table 11: Summary of forecasted market balance for critical raw materials to 2020

Risk of deficit	Balanced market	Risk of surplus
Antimony	Beryllium*	Borates
Coking Coal	Chromium	Lithium
Gallium	Cobalt	Magnesium Metal
Indium	Fluorspar	Natural Graphite
Platinum Group Metals	Germanium	Niobium
Heavy Rare Earth Elements	Magnesite	Light Rare Earth Elements
Silicon Metal	Tungsten	Phosphates

Source: Roskill Information Services (September 2013) and other data in the extended profiles
**no quantitative supply forecast was possible*

4.7 Summary and Conclusions from Criticality Analysis

Twenty one critical raw materials for the EU have been identified from a longer list of fifty four raw materials. This new list includes several new materials, including three that are completely new to the assessment, and only one material moving from critical to non-critical.

The assessment was conducted using the existing EU methodology and thresholds for criticality, combining supply risk and economic importance. According to the methodology, either of the supply risk measures is used to determine criticality, and in contrast with the previous study both measures of supply risk are relevant in determining the 2013 list of critical materials. In this analysis lithium is included in the critical raw materials due its high supply risk linked to environmental performance, whereas the other critical raw materials exceed the threshold in both measures of supply risk.

Overall a greater proportion of raw materials are considered critical in this study, with 39% of the candidate materials classified as critical compared to 29% from the previous study. This is a result of several of raw materials increasing in supply risk, a large proportion of new materials being considered critical, and only one material being removed from the critical list. For comparison, if the new materials are excluded the proportion of critical raw materials remains higher at 35%, counting REEs as a single group. .

Perhaps the most obvious change in the analysis is seen for tantalum, which has dropped significantly in supply risk, removing it from the critical region. This is a reflection of lowering supply risks due to more diverse supply. However it is acknowledged that the tantalum market is highly changeable, therefore large year-to-year changes may be seen for this material. This indicates the importance of keeping the analysis up to date and ensuring data quality remains as high as possible, and ensuring the context of each material is understood

Biotic materials have been evaluated using this methodology, with none found to be critical using this methodology. The methodology and data was deemed adequate for assessing these materials within this context, however further discussion on this topic is provided in Section 6.

Analysis of the data used in this study found an improvement over the previous work, though some key shortcomings remain. These are mainly linked to recycling rates, judgement of substitutability and end use data, as well as consistency across all materials. Relevant recommendations are made in Section 7 and in Annex H.

The supply data demonstrates that little has changed since the last study in terms of the major producing countries, with China dominant for global supply of many materials and particularly the critical raw materials. Countries such as Brazil, DRC, Russia, South Africa, and the USA remain important for the supply of critical raw materials, while others such as Australia, Canada, Chile and Mexico are important to the overall supply of raw materials identified in this study.

An analysis of future global supply and demand trends has identified several different scenarios to 2020 for the critical raw materials. Trends vary across the range of materials, with increasingly tight supply predicted for antimony, indium, PGMs and silicon metal. Other predictions vary in the short to longer term, for example heavy rare earths, gallium, and magnesite, which all switch between surpluses. A more complete picture for each is provided in the extended profiles for the critical raw materials.

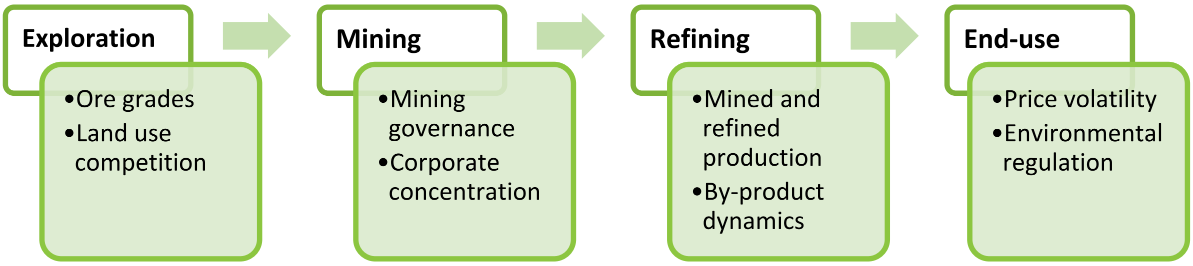
Overall recommendations from this study are made in Section 7, with quantitative methodological recommendations made in Annex H.

5 Possible Influences on Criticality

5.1 Introduction

As described in the previous sections, the methodology for determining the EU list of critical raw materials has remained fixed for this study. This allows direct comparison with the existing study undertaken by the Ad-hoc Working Group in 2010.[a] However, it is recognised that there are a wide range of factors that are not directly taken into account by this methodology that potentially influence the criticality of raw materials, and these may either increase or decrease the relative criticality. A review of other relevant studies, feedback from the previous study, input from the Commission and responses by the AHWG and other stakeholders was used to compile a list of further influences on criticality. Eight influences have been examined in relation to criticality and the critical raw materials, loosely fitting in with separate stages of the abiotic materials supply chain (Figure 12).

Figure 12: Influences on materials criticality discussed in this section.



The intention of this section is not to provide an appraisal of how the quantitative methodology could be changed (though this may be appropriate in some cases). Many of these factors are inherently non-quantitative, and also include risks that are further along the supply chain compared to those used in the methodology. Instead, the discussions provide an overview and more nuanced view of criticality from different perspectives. In addition these influences can be considered on an individual material level. The influences are discussed in the chapters below:

5.2. Exploration:
    5.2.1. Ore grades
    5.2.2. Land use competition
5.3. Mining:
    5.3.1. Mining governance
    5.3.2. Corporate concentration
5.4. Refining:
    5.4.1. Mined and refined production
    5.4.2. By-product dynamics
5.5. End-use:
    5.5.1. Price volatility
    5.5.2. Environmental regulation

The discussions below focus on the abiotic materials due to the nature of the previous study, though reference to biotic materials is made in some chapters, such as price volatility. The methodology for biotic materials is discussed in the Section 6. Through the course of the project possible changes to the quantitative methodology have been identified, applicable to both biotic and abiotic materials. These are captured in Annex H.

---

[a] EC DG-ENTR (2010), Critical raw materials for the EU

5.2 Exploration Stage

5.2.1 Ore grades

The subject of mineral ore grades is of considerable importance to, among others, geologists, mining and refining organisations. However, its influence on raw materials criticality must be carefully explored to understand if and how criticality and particularly supply risk might be influenced. Several considerations of how ore grades could influence criticality in relation to the EU methodology and how this might be gauged are discussed below. These initially refer to discovered ore grades in the geological availability section; in the later points processed ore grades are discussed.

Geological availability

The previous EU critical raw materials study[a] investigated the inclusion of reserve and resource estimates as a measure of geological availability.[b] However, it was ultimately dismissed as a suitable indicator to measure raw materials criticality with the scope of the work. This was because the timescales associated with geological availability were deemed as being too long for the horizon of this particular study. In addition, the published geological reserves estimates were thought not to reflect the total amount of a mineral that is potentially available. For example, there is not uniformity in reporting resources; depending on circumstance some mining companies may only publish reserve estimates to cover their short-term needs whilst others report longer term figures using accepted reporting standards. In addition, lower-grade or more complex ores become economic to process as technological developments are made. This initiates production from deposits that would previously have not been considered for exploitation, making a snapshot view unreliable.

Environmental impact of processing

Ore grade data could serve as a proxy for environmental impact or refining cost, on the basis that lower processed ore grades require additional energy, water and chemicals in their mining and processing, perhaps increasing the supply risk associated with environmental impact. However, ore grades are only one factor amongst many that determine environmental impact or cost. One example of these features is illustrated by lithium, for which two main processing routes currently exist. These are evaporation from South American brines such as in Chile and the mining and process of hard-rock deposits such as in Australia. The brine process involves much lower grade “deposits”, but has a lower energy intensity and very large available reserves. In the case of industrial minerals grades are more closely linked to the quality of the mineral. This means that a range of products with different specifications can be produced from the same deposit. In addition, consideration of by-products and co-products is required. For example sedimentary phosphate deposits may contain low concentrations of waste uranium and cadmium, which has a consequent environmental impact for treatment. Therefore, overall it is difficult to accurately evaluate how this might influence criticality for each different ore grade and type.

Some environmental impact data for metals and minerals is available from “cradle-to-gate” life cycle inventories (LCIs). However, such data ignores both the use and end-of-life phases of environmental impact; this can significantly offset the primary processing stage such as through enabling energy efficient products or from effective recycling at the end-of-life. In addition, some of the available data contained is over 10 years old, and may not be representative of the current situation.[c] A lifecycle analysis measure was considered in the previous work, but ultimately dismissed due to these concerns.

Cross-material comparison

It is possible to collect data on the typical ore grade of various metals and minerals contained within deposits that are currently commercially mined. High-level data on ore grades are available from

---

[a] EC DG-ENTR (2010), Critical raw materials for the EU – report of the ad-hoc working group on defining critical raw materials

[b] Definitions for deposits, reserves and resources are provided in the glossary

[c] EC-JRC (2013), Critical Metals in the Path towards the decarbonisation of the EU Energy Sector – see Annex 2 of referenced report – Specific Impact of Materials

geological surveys and many mining companies, which summarise typical ore grades across a number of metals and minerals[a] (presented as typical ranges rather than as world averages).
Industrial minerals and base metals generally have higher ore grades than precious or by-product metals. However, as an overview some key complexities such as the type or quality of ore mined and processed, detail of the mining and refining processes and information on the presence of key impurities have not been addressed here.

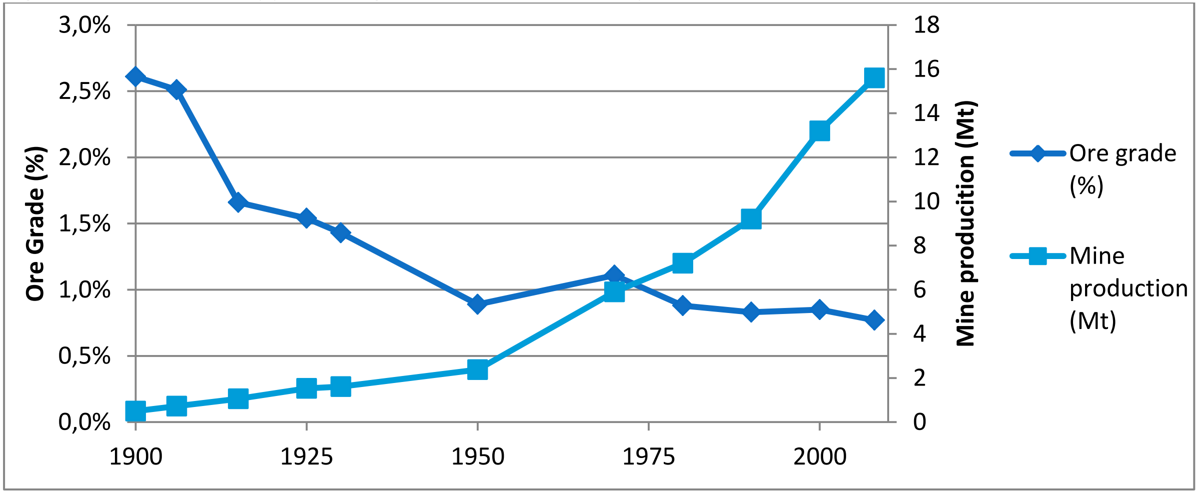
Publicly available and comprehensive data for a wide range of metals and minerals have not been identified in the course of this research, although private databases may exist. A comprehensive study on ore grades (discovered and processed) may cost significant time and money to undertake, but it is not clear what form the data would take, whether historical statistics would be available or what the data would reveal. In addition there may be access issues associated the commercial sensitivity of this data, preventing a broader picture to be drawn.

Trends in processed ore grades

It has been noted by some commentators that ore grades of commercially mined deposits have declined over time, and expressed concerns over long term supply. However, these views generally only take into account the changes in processed ore grade. This provides only limited insight, as the viability of a deposit or availability of mineral is not defined by the ore grade alone. For example, technical progress means that a greater range of ore grades become economic to mine over time, expanding potential supply.

Copper ore grades are used as an example here as they have received considerable coverage in the past. In a review article by Crowson, the data indicate average yields of copper ore are currently less than 1%, compared to 2% around 100 years ago and 8% 200 years ago.[b] A similar trend is observable for large mines such as Bingham Canon, Chino and El Teniente, all of which have been operational for at least the last 100 years. Crowson, however, argues that the trend has started to plateau as large, but low grade, copper porphyry deposits are increasingly exploited.

Figure 13: Trends in copper ores grades and world mine production since 1900



Source: Crowson P. (October 2011), Changing copper yields and ore grades; Mining Journal & additional USGS mine production data

Figure 13 compares the trend in copper ore grades since 1900 against world mine production, and the negative correlation between these two trends is striking. Over this period, world mine production of copper has increased more than 30-fold, which has been accompanied by a search for new sources of copper in order to keep up with rising world demand. Additionally, data on prices show that, in real

---

[a] See for example, BGS Mineral Profiles and BRGM Minéral Info Report Series
[b] Crowson P. (October 2011), Changing copper yields and ore grades; Mining Journal

terms, copper prices have fallen over the period,[a] which provides further evidence for the role of technological innovation. There is therefore no evidence to show that changes in ore grades have a significant influence on supply matching demand.

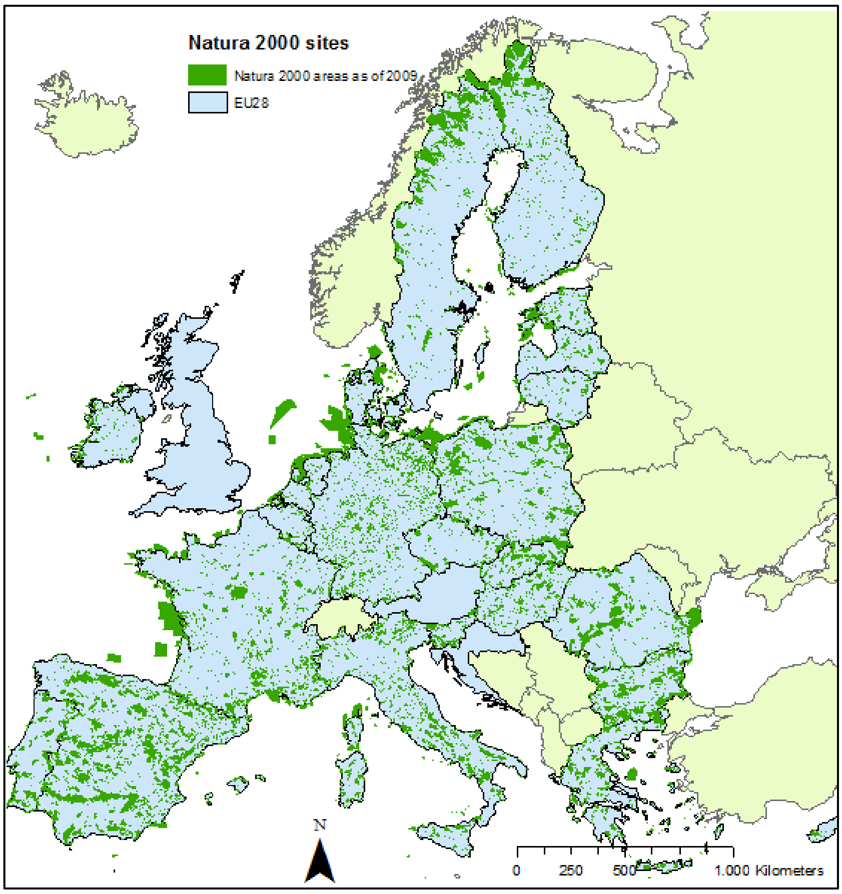
Conclusion

In summary, ore grades are an interesting and important topic for on-going research to broaden geological knowledge, and for the continuing exploitation of mineral resources. For the purpose of the EU study they are considered to be not directly relevant to criticality, though for some studies which consider a longer timeframe (over several decades in some cases[b]) it is considered appropriate. However, as discussed above, careful justification and consideration is required for inclusion. In addition, the discussion above outlines that there is no strong rationale or sufficient available data to widely consider ore grades in this context, either discovered or processed, over the materials studied, nor is it relevant to all materials. Therefore, whilst ore grades should be kept in mind during wider discussions, they are less relevant to the existing EU criticality assessment methodology.

5.2.2 Land use

The potential impact of land use on the criticality of the raw materials depends on the degree of competition of a potential resource site with other land uses. Generally, natural land is more likely to be converted to an extraction site than artificial surfaces, where a use for settlement and industry has been established and were the soil is usually sealed with concrete or asphalt. However, legal constraints play an important role as many natural areas are protected according to national or European law.

Figure 14: Natura 2000 sites.



---

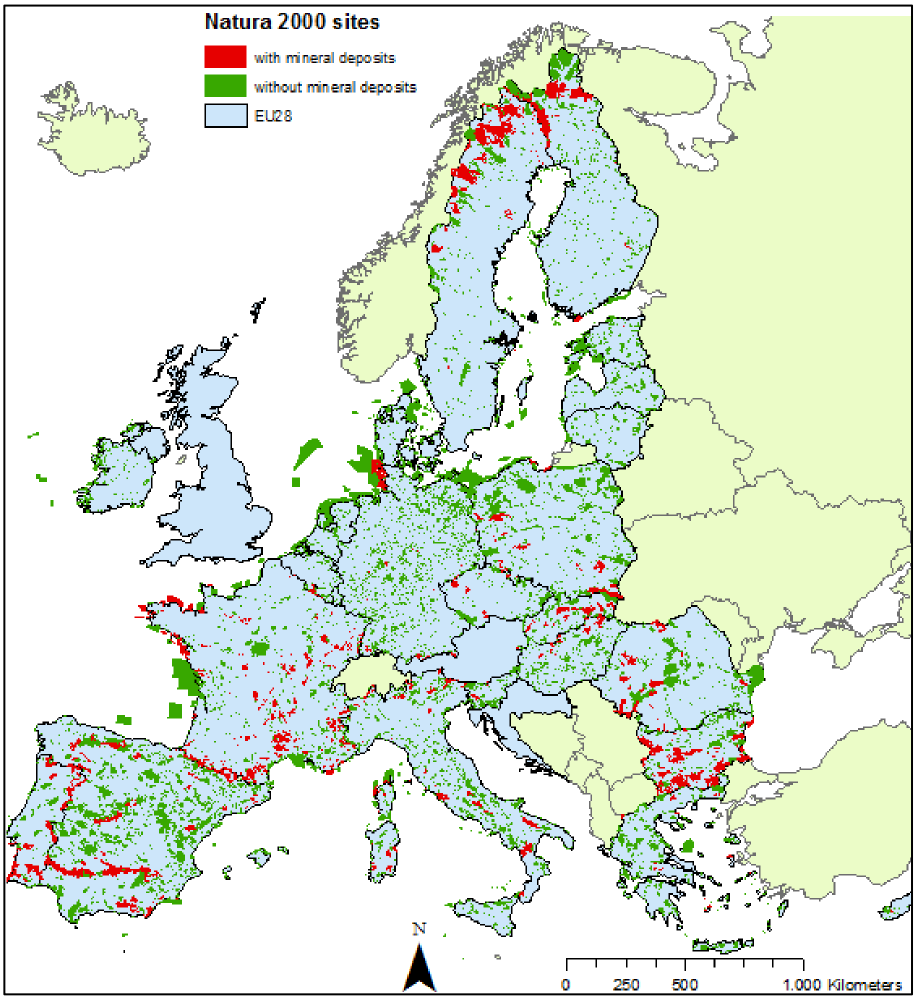
[a] USGS (2012), Historical Statistics for Mineral and Material Commodities in the United States [accessed February 2013]

[b] Graedel *et al*, Environmental Science & Technology (2011), Methodology of Metal Criticality Determination

The main legal constraint in the European Union for natural land is the Natura 2000 ecological network of protected areas. According to the European Environment Agency (EEA), it is set up to ensure the survival of Europe's most valuable species and habitats. The network is designated under two directives, the Birds and the Habitats Directive (Special Protection Areas, Sites of Community Importance, Special Areas of Conversation). It comprises 26,000 sites in twenty eight member states and covering 18% of the total land of the EU. The sites are determined by the national authorities and the spatial data is validated by the EEA.[a] However, beyond the European regulations, there are also protected areas according to national law, which is partly congruent with the Natura 2000 sites and partly covers additional areas. In Germany, for example, these area types are national parks, nature protection areas, biosphere reserves, landscape protection areas and natural parks. The distribution of Natura 2000 sites (as of 2009) is shown in Figure 14

The EU-wide nature protection system Natura 2000 often protects species which live in stone quarries and pits and are therefore directly affected by resource extraction. In order to explore the situation of land competition in Europe geographically, NATURA 2000 data have[b] been intersected with data from the ProMine Portal.[c] Figure 15 highlights all those Natura 2000 sites in which mineral deposits are found.[d] These are approximately 3 % of the sites (700 of 24700 sites), which have of course different area sizes.

Figure 15: Natura 2000 sites with and without mineral deposits in Europe



---

[a] This data is generalized to a scale of 1/100,000 and some member states have submitted sensitive information that has been filtered out of the database.

[b] http://discomap.eea.europa.eu/ArcGis/rest/services

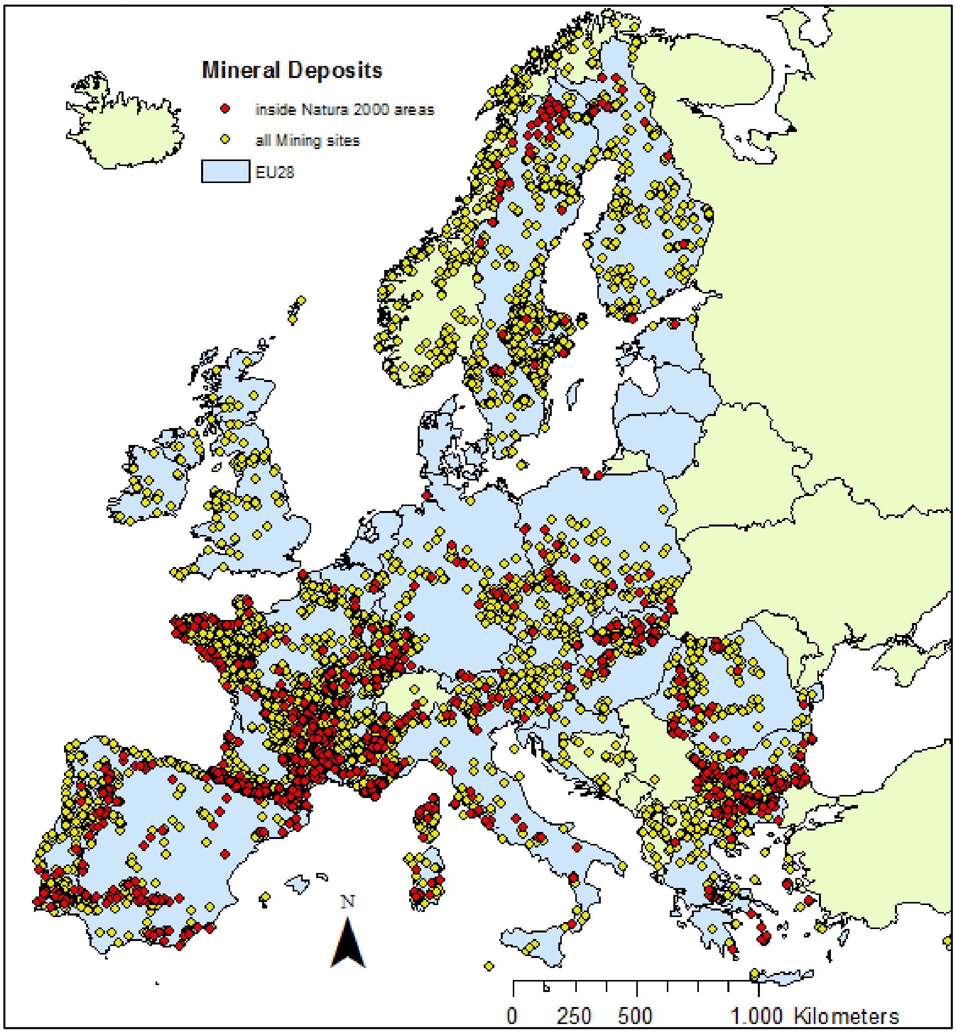
[c] http://ptrarc.gtk.fi/ProMine/default.aspx

[d] (Potential) Mineral extraction sites were derived from the ProMine database and include operating and currently not operating sites, as well as sites under development. See Annex G for details on the classification of sites.

Joint agreements have been made on a national level between nature conservation organisations and the non-energy extractive industry (NEEI), and a guidance document (not legally binding) on this relationship has been published by the European Commission[a]. It constitutes a compromise and generally states that in general non-energy resource extraction is not excluded in or close to Natura 2000 sites. In addition, the NEEI commits itself to re-cultivate exhausted extraction sites with the objective to restore the original habitats and populations. It recommends the following procedure:

1. **Screening:** Plans as a framework for development consents and individual projects will be screened if they are likely to have a significant effect on the Natura 2000 sites. If this is the case, an appropriate assessment is needed.
2. **Appropriate Assessment:** Its steps comprise the definition of the study area, identification of the habitats and species to be considered as base for the assessment of the effects and a design of preventive and mitigation measures.

Figure 16: Mineral Deposits in and outside Natura 2000 areas



If adverse effects on the integrity of Natura 2000 sites cannot be excluded by certain plans or projects, an exceptional authorisation may be granted. The conditions are that the competent authorities analyse and demonstrate the lack of less damaging alternatives and the need of the plan or project concerned for imperative reasons of overriding public interest.[b] This requires a good knowledge of the location of the mineral resources as well as information regarding their access, quality and feasibility for the mineral

---

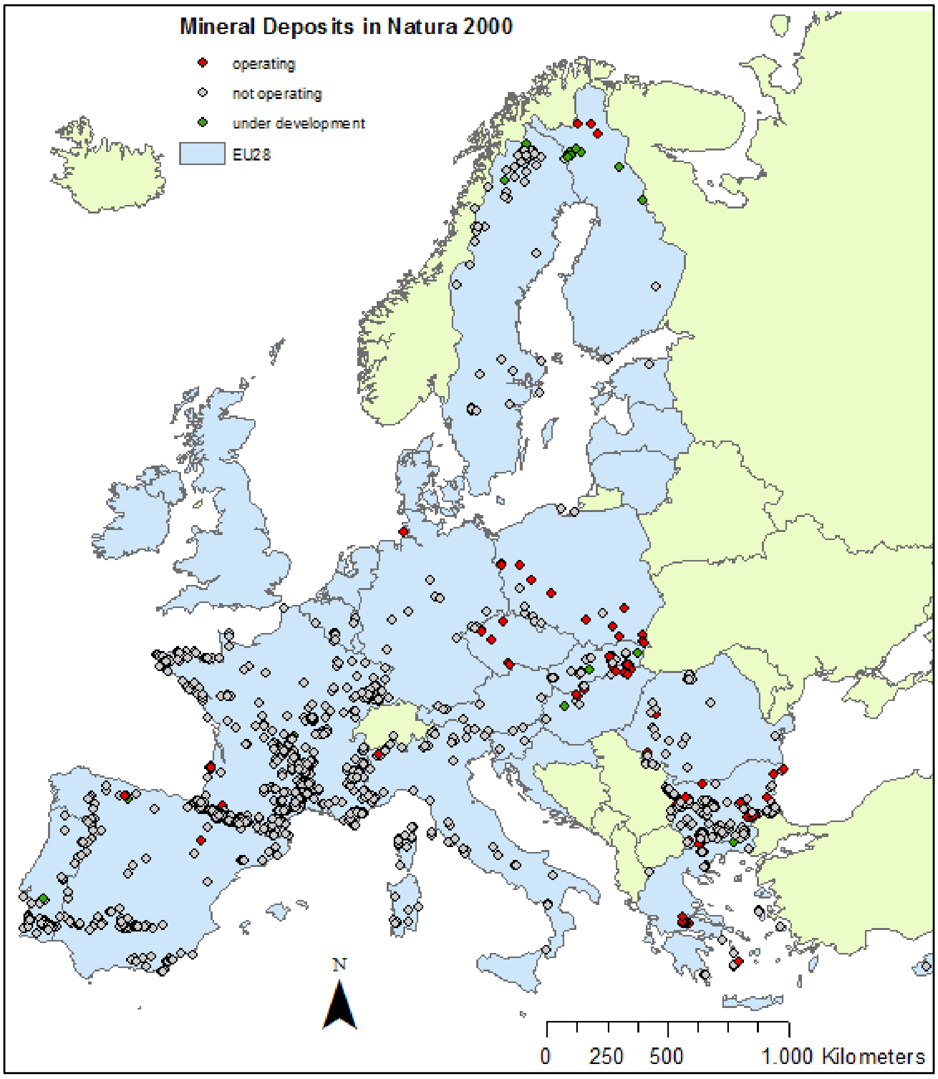
[a] EC (2011): Guidance-Document. Non-energy mineral extraction and Natura 2000. http://ec.europa.eu/environment/nature/natura2000/management/docs/neei_n2000_guidance.pdf

[b] Artcile 6.4 of the Habitats Directive

extraction. In case the exception applies, compensatory measures must be implemented to ensure that the overall coherence of Natura 2000 is protected.

Although Figure 16 offers a first impression as to the degree and location of conflicting land uses, further insights can be obtained by differentiating the data by their different statuses, i.e. operating mines, non-operating mines and those which are currently under development. Figure 17 shows that only 85 of the 1435 relevant mineral deposits (shown in Figure 16) are currently operating, 24 are under development and the rest is not operating anymore (abandoned or exhausted). The operating mines are mainly located in Poland and Bulgaria. Inspection of Figure 17 thus suggests that land use competition between mining and natural protection is not a crucial limiting factor in access to raw materials within the EU.

Figure 17: Mineral Deposits in Natura 2000 areas



5.3 Mining Stage

5.3.1 Mining Governance

An additional concern raised, linked to supply risk, is the influence of mining governance within supplying countries. In the existing EU criticality methodology the World Governance Index (WGI) is used as a measure of the political risk associated with a country, and is assumed to be representative for the mining industry for the purposes of this study. The WGI has the benefit of being widely accepted, comprehensive and regularly updated. The Index comprises of factors falling into six categories, each of which can be viewed as influencing the mining and extraction industries[a]:

- Voice and accountability
- Political stability and absence of violence
- Government effectiveness
- Regulatory quality
- Rule of law
- Control of corruption

A figure for each of these is calculated by aggregating a group of sub-factors, gathered from various different sources. The scores for the categories are rescaled and combined using a statistical methodology to produce an overall score for each country.

However, it is useful to examine more specific mining related schemes related to countries. Subscription to or being assessed positively in these schemes may be viewed as reducing the criticality of supply from specific countries due to greater transparency or certainty in the mining industry. Three examples of schemes for countries have been identified:[b]

- Extractive Industries Transparency Initiative
- Revenue Watch Institute's Resource Governance Index.
- Fraser Institute's Mining Policy Potential Index

Table 12: Twenty most important producing countries for abiotic materials and critical raw materials

Country	Materials Supplied (Out of 51)	Overall % Contribution	CRMs Supplied (Out of 21)	% Contribution to CRM supply
China	45	30%	19	47%
USA	34	9.2%	10	9%
Russia	40	4.7%	16	4%
Brazil	33	4.4%	12	6%
Australia	31	3.9%	11	2%
South Africa	26	3.9%	9	6%
Chile	16	3.3%	3	3%
Canada	28	2.7%	11	2%
India	27	2.3%	8	2%
Turkey	24	2.1%	7	2%
Japan	16	1.5%	2	1%
France	11	1.6%	1	0%
Germany	15	1.3%	3	1%
Indonesia	14	0.9%	2	0%
Kazakhstan	23	1.4%	7	2%
Mexico	23	1.3%	5	1%
Peru	17	1.3%	3	0%
DRC	8	1.1%	3	3%
Italy	11	0.9%	0	0%
Thailand	18	0.3%	4	0%

---

[a] http://info.worldbank.org/governance/wgi/resources.htm#methodology

[b] Similar schemes also exist for companies, for example see Global Reporting Initiative (2011), Sustainability Reporting Guidelines & Mining and Metals Sector Supplement,

To provide a baseline for comparison the twenty largest producing countries of the fifty one abiotic materials included in this study have been identify, and relevant statistics from supply data extracted, Table 12. It should be noted that due to limitations with data some of the production statistics refers to refining rather than mining, therefore care is needed when interpreting these results.

An analysis of each scheme has been produced and compared with the information used within the EU material criticality assessment to provide further insight on this analysis, and to provide an overview of related issues that could influence access to materials. None of these are as comprehensive or as broad as the WGI, however they provide some insight into extractive industry specific influences and concerns, or demonstrate which countries have the lowest risk for developing supply. Whilst these reflect issues associated with mining, it should also be noted that the WGI provides a high level, broad assessment of political risk across all territories of relevance to this study, accounting for a wider range of influences. This allows for data in the study which reflects refining or production capacity. Therefore it remains highly relevant to this work and assessment methodology.

EITI (Extractive Industries Transparency Initiative)

The EITI is a global scheme launched in 2002 to promote revenue transparency and accountability in the extractive industries sector. The overall aims are to ensure citizens of resource-rich countries benefit from extraction of natural resources, and reduce or stop suffering due to poor governance in the form of conflict and corruption. Involvement in this scheme provides information on the governance of the extractive industries within a country; this may be mining or other sectors in the extractive industry. Therefore supply of materials, including CRMs, from EITI countries could be viewed to reduce supply risk. For example, countries involved in the EITI can be compared with the major producing countries identified within this study to provide insight into the potential role for the EITI in securing access to materials.

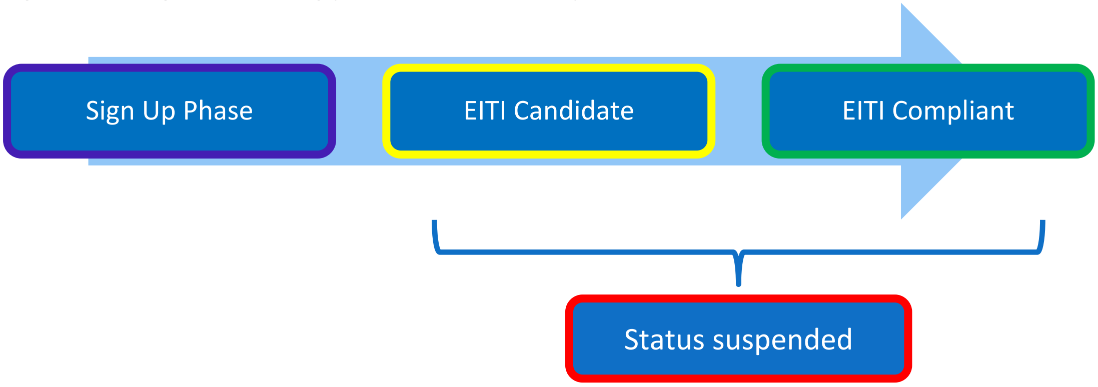
EITI implementation mechanism

For a country to be EITI compliant, the scheme requires that company payments and government revenues for oil, gas and mining are monitored and reconciled at the country level. Countries are required to publish an annual EITI report which contains this information on payments, as well as contextual information about the extractive sector. The reporting is conducted by a group of stakeholders from government, industry and civil society. Therefore there two key components to the initiative:

- **Transparency:** Companies disclose their payments to the government, and the government discloses its receipts. The figures are reconciled and published in annual EITI Reports alongside contextual information about the extractive sector.
- **Accountability:** A multi-stakeholder group with representatives from government, companies and civil society is established to oversee the process and communicate the findings of the EITI Report

Reporting methodology can be tailored for each country's circumstance, for instance only reporting on the relevant extractive industry such as the mining sector. Validation through independent assessment is required to provide external assurance of the process.

Figure 18: Diagram outlining process to reach compliance with the EITI standard



Countries participating in the EITI aim to reach EITI complaint status through a formally set out process (Figure 18). The first stage is for a country to reach candidate status through four "sign-up" steps. This involves expressions of commitment, developing the EITI operational mechanisms within the country and finally admission by the EITI board.

To reach compliant status the country must publish its first EITI report within 18 months of reaching candidacy, and commence validation through independent evaluation to demonstrate compliance of EITI requirements with 30 months. The full requirements of the scheme are described by the EITI standard[a], however the seven main components of the EITI can be summarised:

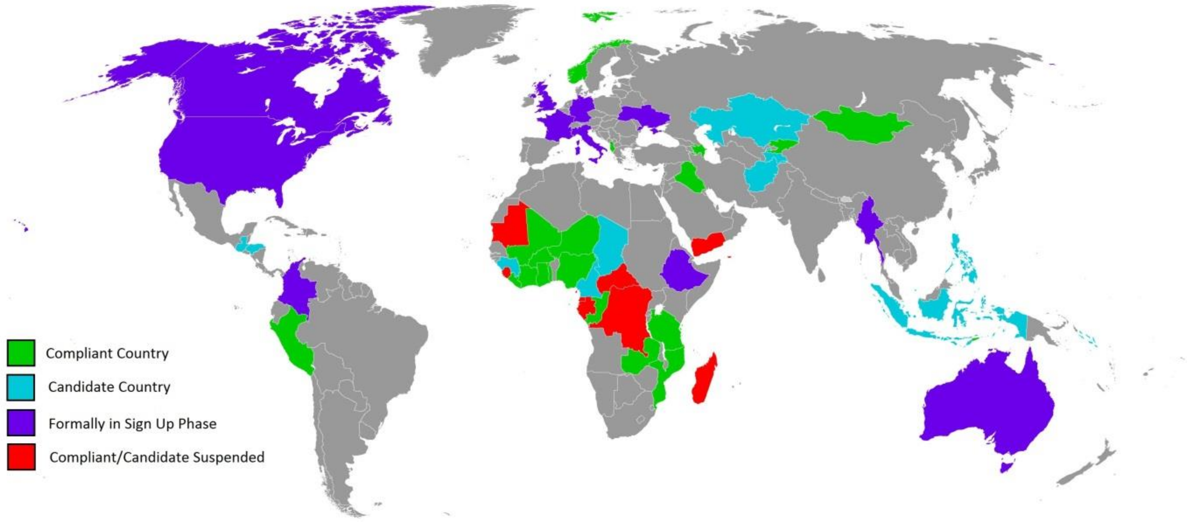
1. effective oversight by the multi-stakeholder group
2. timely publication of EITI Reports
3. EITI Reports that include contextual information about the extractive industries
4. the production of comprehensive EITI Reports that include full government disclosure of extractive industry revenues, and disclosure of all material payments to government by oil, gas and mining companies
5. a credible assurance process applying international standards
6. EITI Reports that are comprehensible, actively promoted, publicly accessible, and contribute to public debate
7. that the multi-stakeholder group takes steps to act on lessons learned and review the outcomes and impact of EITI implementation.

A country may become compliant or remain a candidate or have candidate status suspended or revoked. Further validation of compliant countries must take place every three years. Compliant countries may also have their status suspended.

Analysis of EITI Countries

The EITI scheme provides information on candidate, compliant and suspended countries, as well as information on those who have formally expressed interest in joining the process (i.e. in the sign up phase). 51 countries are involved directly in the EITI, with up to 41 reporting on mining.[b] Figure 19 shows the distribution of countries participating in the EITI that specifically report on mining.[c]

Figure 19: Geographical representation of counties participating in the EITI specifically for mining†



†As of July 2013. Countries in Sign Up Phase may not have specified if the mining industry will be reported on.
Source: EITI with own analysis.

---

[a] http://eiti.org/eiti/requirements
[b] A complete list is provided in Annex G
[c] Some countries in the Sign Up Phase may not have specified which industry sectors are relevant to their interest.

At present, sixteen countries have achieved compliant status, with a further twenty two countries working towards compliant or candidate status. The countries underlined in the table are those which are also in the list of most important producers from the data gathered. This group of nine countries involved in the EITI represents 26% of overall supply and 16% of critical raw material supply (this excludes the Democratic Republic of the Congo (DRC) as it is under suspension from the EITI). The contribution to overall supply each category contributes is also show, demonstrating that only a small proportion of supply arises from compliant countries at present.

Table 13 shows the countries from the most important twenty producers which are not directly involved in the EITI at present. These countries, along with the suspended DRC, account for 58% of production overall production and 75% of total critical raw material production, indicating that the majority of materials are produced outside the countries directly involved in the EITI. However, countries such as China and other G8 nations have expressed their support for the scheme, indicating the wider and longer term potential of this scheme.

Table 13: Status of counties involved in the EITI (mining). Those underlined are in the list of most important producing countries across all materials studied (by overall % contribution)

EITI Status	Countries	Count	% Overall Supply
Compliant	Albania, Azerbaijan, Burkina Faso, Côte d'Ivoire, Ghana, Kyrgyzstan, Liberia, Mali, Mauritania, Mongolia, Mozambique, Niger, Peru, Tanzania, Togo, Zambia	16	2.8%
Candidate	Afghanistan, Cameroon, Chad, Guatemala, Guinea, Honduras, Indonesia, Kazakhstan, Philippines, Solomon Islands, Tajikistan	11	3.1%
Sign Up Phase	Australia, Canada, Colombia, Ethiopia, France, Germany, Italy, Myanmar, Ukraine, United Kingdom, USA	11	22.6%
Suspended	Central African Republic, Democratic Republic of the Congo, Gabon, Madagascar, Sierra Leone	5	1.5%

Source: EITI with own analysis.

Table 14: Most significant producing countries (by overall % contribution) not directly involved in the EITI

	Countries	Count
No Formal Status	Brazil, Chile, China, Greece, India, Japan, Mexico, Russia, South Africa, Turkey	10

Source: EITI with own analysis.

At present Peru is the only major producer that is fully compliant with the EITI, though several others are engaged in the process. The EITI has been in operation for around 10 years, with developing nations the first to sign up to the scheme, most likely to alleviate concerns over transparency and accountability. This situation is reflected by comparing the EITI compliant countries with the ranking of WGI (Table 15).

Table 15: WGI Ranking for the sixteen EITI Compliant countries, each ranked out of 210

Country	2012 WGI Ranking	Country	2012 WGI Ranking
Albania	111	Mauritania	172
Azerbaijan	170	Mongolia	113
Burkina Faso	130	Mozambique	121
Côte d'Ivoire	188	Niger	149
Ghana	85	Peru	110
Kyrgyzstan	169	Tanzania	126
Liberia	162	Togo	174
Mali	137	Zambia	120

Source: EITI with own analysis.

Almost all fall into the lower half when the WGI for the 210 economic zones are ranked. However, a growing number of developed countries are becoming involved, with large producing countries such as Australia and the United States working towards candidate status. Table 16 shows the rankings of countries that make the largest contributions to supply that are not signed up to the EITI. These show greater variations in ranking, though a significant proportion still rank in low positions.

Table 16: WGI Ranking of top 20 producing countries not involved in the EITI, or suspended

Country	WGI Ranking (out of 210)	Country	WGI Ranking (out of 210)
Brazil	86	Japan	29
Chile	28	Mexico	105
China	147	Russia	164
DRC*	207	South Africa	77
Greece	73	Turkey	99
India	123		

**Status Suspended*

Overall, the EITI provides insight into the current status of the extractive and specifically mining industries in various countries, showing a willingness to demonstrate transparency and accountability. At present the subscribers are primarily developing nations that are less significant in terms of raw materials supply, contributing supply to twenty nine of the raw materials analysed and ten critical raw materials, accounting for 2.8% and 1.2% of supply of these groups respectively.

Table 17 shows the contribution of the EITI compliant countries to supply of all raw materials. The most significant contributions are made by Mozambique (18% tantalum), Peru (17% silver, 13% tin, 12% zinc, 8% copper, 6% gold, 6% borates), Mongolia (fluorspar 7%), Zambia (6% cobalt, 4% copper).

Table 17: Raw material supply from EITI compliant countries. Underlined critical materials to the EU

Material	% Contribution	Material	% Contribution	Material	% Contribution
Tantalum	18%	Manganese	3%	Barytes	0.7%
Silver	17%	Selenium	2%	Bentonite	0.4%
Gold	17%	Aluminium	1%	Nickel	0.4%
Copper	13%	Chromium	1%	Phosphate Rock	0.4%
Tin	13%	Coking Coal	1%	Talc	0.3%
Zinc	13%	Diatomite	1%	Bauxite	0.2%
Molybdenum	11%	Tungsten	1%	Limestone	0.2%
Fluorspar	7%	Iron	1%	Clay	0.1%
Borates	6%	Antimony	0.8%	Niobium	0.05%
Cobalt	6%	Beryllium	0.8%		

Source: Analysis from supply data sources in Annex C

An analysis of contribution to critical raw material supply is shown in Table 18. This shows the large variation in supply of critical raw materials involved in the EITI. Overall, there is little coverage, particularly from the compliant countries. Fluorspar, borates and cobalt are shown have the highest contribution from compliant countries.

Table 18: Summary of supply of critical raw materials from countries involved in the EITI scheme, with % supply. (neg. = negligible).

Material	Compliant	Candidate	Sign Up	Suspended	% (excl suspd.)
Antimony	Kyrgyzstan (0.6%), Peru (0.2%)	Tajikistan (2%), Kazakhstan (1%)	Australia (0.5%), Canada (neg.)		4%
Beryllium	Mozambique (0.8%)		USA (90%)		91%
Borates	Peru (6%)	Kazakhstan (1%)	USA (30%)		37%
Chromium	Albania (1%)	Kazakhstan (20%), Philippines (neg.), Afghanistan (neg.)	Australia (0.5%)	Madagascar (0.3%)	22%
Cobalt	Zimbabwe (6%)	Indonesia (2%), Philippines (2%)	Australia (4%), Canada (4%)	DRC (56%), Madagascar (0.2%)	18%
Coking coal	Mongolia (1%)	Kazakhstan (1%)	Australia (17%), USA (8%), Canada (3%), Ukraine (2%), Germany (1%), Colombia (neg.), UK (neg.)		33%
Fluorspar	Mongolia (7%)		Germany (1%), UK (0.5%)		8%
Gallium		Kazakhstan (6%)	Germany (10%), Ukraine (4%)		20%
Germanium			Canada (17%), USA (15%)		32%
Indium			Canada (10%)		10%
Lithium			Australia (22%), USA (7%)		29%
Magnesite		Guatemala (neg.), Philippines (neg.)	Australia (1%), Canada (1%)		2%
Magnesium		Kazakhstan (3%)	Ukraine (0.3%)		3%
Natural Graphite			Canada (2%), Ukraine (1%)	Madagascar (0.5%)	3%
Niobium	Mozambique (1%)		Canada (7%), Ethiopia (neg.)	DRC (neg.)	8%
PGMs			Canada (3%), USA (2%)		5%
Phosphate Rock	Togo (0.4%), Burkina Faso (neg.)	Kazakhstan (1%), Indonesia (neg.), Philippines (neg.)	USA (17%), Australia (1%), Colombia (neg.)		20%
REE			USA (6%)		6%
Silicon			USA (9%), France (7%)		16%
Tungsten	Peru (1%), Kyrgyzstan (0.1%), Mongolia (neg.)		Canada (1%), Australia (neg.), Myanmar (neg.)	DRC (0.5%)	2%

Supply from the candidate countries is also relatively low, with the exception of chromium and gallium supply from Kazakhstan. By contrast, many of the sign up countries have significant production volumes of the critical raw materials, particularly beryllium due its supply from the USA, as well as borates, coking coal, and germanium. In general the other materials are poorly represented, but those that are particularly low (less than 5% of supply from the first three categories) include antimony, magnesite, magnesium, natural graphite, and tungsten. This is generally because the existing production is associated with one or two countries which sit outside the EITI scheme. It is also of note that over half of cobalt supply arises from the DRC, a suspended country.

This analysis demonstrates the variability of uptake and coverage of the EITI scheme is also seen at a materials level as well as a country level. It is difficult to gauge the immediate impact to supply across the full extent of materials analysed within this study due to this variability. Even for those with a large contribution from countries

It should be noted that this scheme specifically focuses on the mining and extractive industries, therefore will not necessarily tie into analysis based on refining, which has been used for certain materials. Therefore cannot be universally applied to all materials in this study.

Conclusions

The analysis above demonstrates that the EITI scheme is unlikely to strongly influence the criticality of materials at present, as will not adjust the supply risk of materials significantly. This is primarily due to the low geographical and materials coverage. However, wider adoption of this scheme in the future may lead to a greater relevance of this scheme on criticality.

The scheme does provide some insight into the supply of the raw materials, demonstrating that most materials and the vast majority of critical raw materials are produced from countries outside this scheme, notably China, Brazil and South Africa.

Despite the low uptake, this analysis may provide useful information on production in the future, as a greater number of countries engage with the EITI process. Particularly those that do supply raw materials and critical raw materials, a positive impact on materials criticality may be seen as supply risks may be reduced from particular countries. In the short term sourcing of critical raw materials in particular from countries in the EITI scheme could be explored in certain cases as a way to reduce supply risk, for instance for borates, cobalt and fluorspar. However comparison against the WGI demonstrates that care is needed as other factors need consideration.

Revenue Watch Institutes' Resource Governance Index (RGI)

The Resource Governance Index (RGI) is published by the Revenue Watch Institute (RWI) to indicate the quality of governance in the oil, gas and mining sectors of resource rich countries. This forms part of the overall aims of the organisation to promote the effective, transparent and accountable management of natural resources.

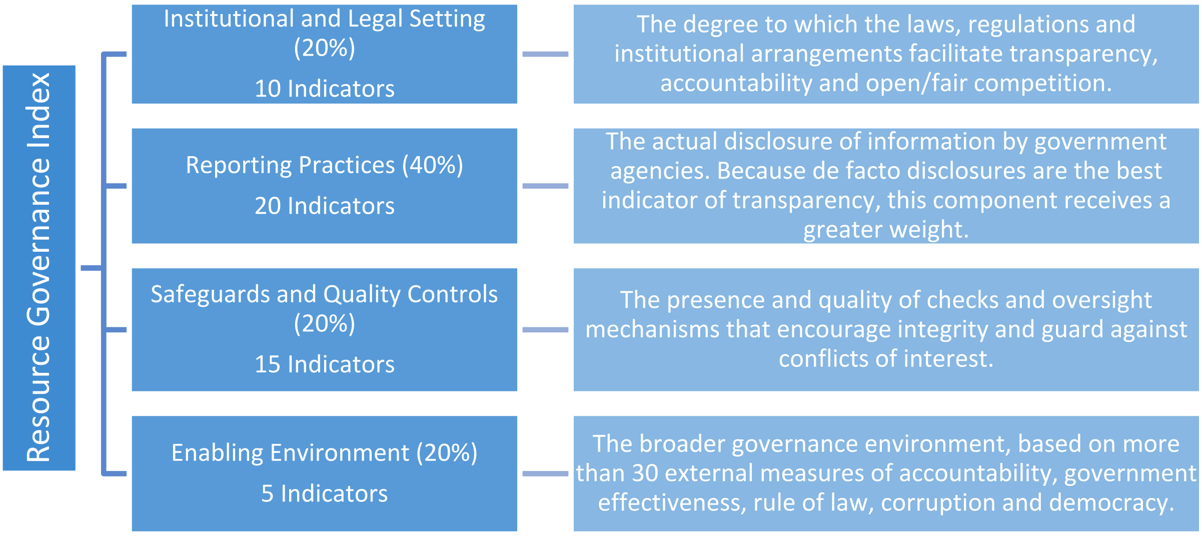
RGI Methodology

The RGI measures the quality of governance in the oil, gas and mining sectors of fifty eight resource rich countries.[a] The Index is formed of four components, each comprising of a number of indicators addressing specific issues (Figure 20). The first three are extractive industry specific. These are assessed through experts engaging in a data gathering and answering a standard set of questions. The results of this exercise are peer reviewed to ensure consistency. The final component, Enabling Environment, addresses each country's broader governance environment. These components are combined using a weighted average to give the overall normalised RGI.

---

[a] The 2013 Resource Governance Index, Revenue Watch Institute, 2013

Figure 20: Composition the RGI



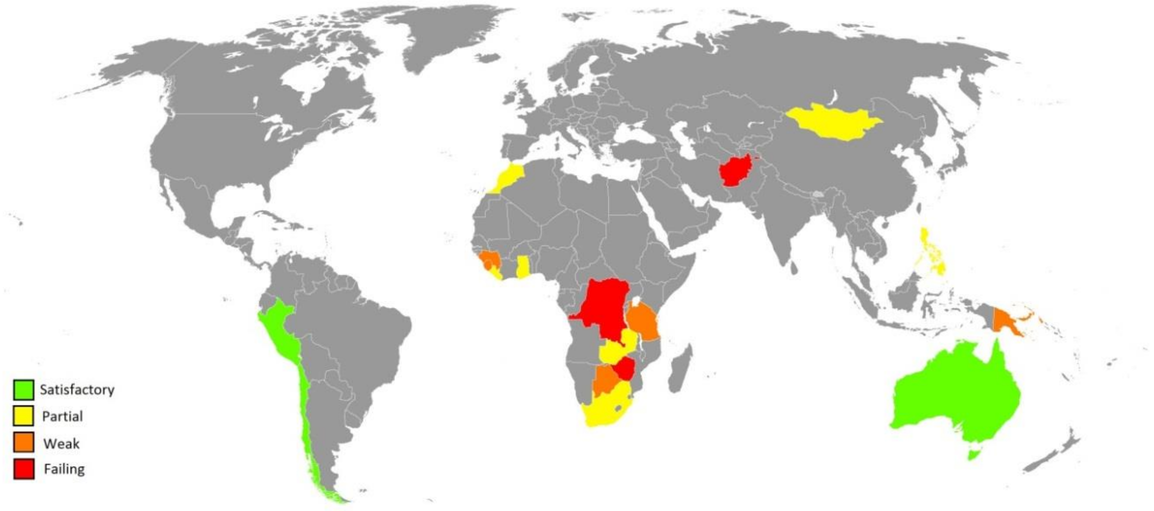
Source: Revenue Watch Institute

Within the analysis, hydrocarbon or mineral production are assessed depending on the country. If both are significant for the country, the sector with the highest revenue has been selected for reporting. As a result, from the fifty eight countries surveyed eighteen reported on mining.[a]

Analysis of RGI

Within the analysis the RWI identifies four categories of countries according to their associated RGI score; satisfactory (71-100), partial (51-70), weak (41-50) and failing (0-39). This roughly splits the countries into quarters. Figure 21 shows the geographical representation of these assignments for the mining countries.

Figure 21: Geographical representation of the RGI for countries surveyed for mining



Source: Revenue Watch Institute with own analysis

Of the eighteen countries assessed three are categorised as satisfactory (Australia, Chile and Peru) and three are categorised as failing (Afghanistan, Democratic Republic of the Congo and Zimbabwe).

---

[a] The value for Western Australia is assumed to be representative for all of Australia for this analysis.

Table 19: Comparison of RGI with WGI ranking and materials production, critical raw materials have been underlined

Country	RGI	RGI Category	WGI Rank (Out of 210)	Most significant raw material production
Afghanistan	33	Failing	209	None
Australia	85	Satisfactory	10	Bauxite (34%), Lithium (22%), Iron (21%), Titanium (21%), Manganese (19%), Coke (17%), Zinc (12%), Nickel (12%), Gold (10%)
Botswana	47	Weak	62	Nickel (1%)
Chile	75	Satisfactory	28	Rhenium (61%), Lithium (48%), Copper (34%), Molybdenum (15%), Borates (10%)
Democratic Republic of the Congo	39	Failing	207	Cobalt (56%)
Ghana	63	Partial	85	Gold (3%), Manganese (3%)
Guinea	46	Weak	192	Bauxite (8%)
Liberia	62	Partial	162	None
Mongolia	51	Partial	113	Fluorspar (7%)
Morocco	53	Partial	124	Phosphate Rock (15%), Barytes (7%), Cobalt (3%), Fluorspar (2%)
Papua New Guinea	43	Weak	160	Gold (2%)
Peru	73	Satisfactory	110	Silver (17%), Tin (13%), Zinc (12%), Molybdenum (10%), Copper (8%), Borates (6%), Gold (6%)
Philippines	54	Partial	138	Nickel (16%), Tellurium (4%), Selenium (3%), Cobalt (2%)
Sierra Leone	46	Weak	157	Bauxite (1%), Titanium (1%)
South Africa	56	Partial	77	PGMs (61%), Chromium (43%), Vanadium (37%), Titanium (20%), Manganese (19%), Gold (7%), Fluorspar (3%)
Tanzania	50	Weak	126	Gold (2%)
Zambia	61	Partial	120	Cobalt (6%), Copper (4%)
Zimbabwe	31	Failing	203	PGM (5%), Chromium (2%)

Comparison of the RGI scores with the WGI rankings demonstrates that the two broadly match each other from the narrow set of countries available (Table 20). Of the countries included only five (Australia, Chile, DRC, Peru, and South Africa) are amongst the most significant producers of raw materials found in this study

Comparison can also made between production across all materials and the critical raw materials. These countries account for 17.4% of overall production considered within this study. The largest coverage is seen for cobalt (73%), lithium (70%), PGMs (66%), rhenium (61%), copper (47%) and chromium (45%). When compared with production of the critical raw materials these territories account for around 16.5% of production (Table 20).

Though the largest contribution is made to cobalt, lithium and PGMs; however, there is a contrast in the status of the producing countries from “failing” for the DRC (cobalt), to “partial” for South Africa (PGMs) to “satisfactory” for Chile (lithium).

Table 20: Comparison of Critical Raw Materials and RGI, weak and failing counties have been highlighted

Material	RGI Counties	Non RGI supply
Antimony	South Africa (2%), Australia (0.5%), Peru (0.2%)	97%
Beryllium	None	100%
Borates	Chile (10%), Peru (6%)	84%
Chromium	South Africa (43%), **Zimbabwe (2%)**, Australia (0.5%), Philippines (0.1%), **Afghanistan (neg.)**	55%
Cobalt	**DRC (56%)**, Zambia (6%), Australia (4%), Morocco (3%), Philippines (2%), South Africa (2%), **Botswana (0.3%)**, **Zimbabwe (0.1%)**	27%
Coking coal	Australia (17%), Mongolia (1%), South Africa (0.3%), **Zimbabwe (0.1%)**	81%
Fluorspar	Mongolia (7%), South Africa (3%), Morocco (2%)	88%
Gallium	None	100%
Germanium	None	100%
Indium	None	100%
Lithium	Chile (48%), Australia (22%)	30%
Magnesite	Australia (1%), South Africa (0.4%), Philippines (0.02%)	99%
Magnesium	None	100%
Natural Graphite	None	100%
Niobium	**DRC (neg.)**	100%
PGMs	South Africa (61%), **Zimbabwe (5%)**	34%
Phosphate Rock	Morocco (15%), South Africa (2%), Australia (1%), **Zimbabwe (neg.)**, Chile (neg.), **Tanzania (neg.)**, Philippines (neg.)	82%
REE	Australia (4%)	96%
Silicon	None	100%
Tungsten	Peru (1%), **DRC (0.5%)**, Australia (neg.), Mongolia (neg.)	98%

Conclusions

Whilst this Index is quantitative and directly related to mining risk, its coverage of eighteen countries precludes it from directly influencing the criticality analysis. If a wide group of countries is surveyed in the future this may allow more direct use of this Index. However, useful comparisons can be made against the WGI, showing similar ranking for counties using both indices. In addition, analysis between the RGI and raw material producing countries can be produced. This shows a variation in coverage over all materials, with some represented well (e.g. cobalt and lithium), but many having no or limited representation. Analysis of critical raw material production shows that with the exception of cobalt, lithium and PGMs, there is little coverage. However, some insight between the production of these materials is given by the difference in classification these countries have been assigned. This could allow EU sources to target supply from particular countries avoiding either failing or weak ranked countries (for instance, source cobalt from alternative countries to the DRC), supporting improvements in certain countries, or requesting that the Index is extended to non-assessed countries to broaden its reach.

Fraser Institute Mining Policy Potential Index

The Fraser Institute, an independent think tank, publishes an annual analysis of mining countries using their in-house Policy Potential Index (PPI).[a] This index measures the overall policy attractiveness to exploration investment across a range of jurisdictions (countries and regions), incorporating fifteen different policy factors such as taxation and regulation. Its purpose is to assess the policies influencing mining in the surveyed jurisdictions, which can act as an indicator on how attractive the policy landscape is to an exploration manager. This is useful when comparing countries with an existing prospecting and mining industry. Whilst this does not directly indicate the risk associated with material production in a country, it provides some scope for understanding where production could most easily be expanded to (from a policy standpoint) to potentially minimise supply risk. Comparison can also be made with the countries found to be most important suppliers within this study.

PPI Methodology

The PPI is a composite index calculated through aggregating 15 separate policy actors which influence corporate decisions to invest in certain areas:[b]

1. Uncertainty concerning the administration, interpretation, or enforcement of existing regulations;
2. Uncertainty over environmental regulations
3. Regulatory duplication and inconsistencies
4. Legal system
5. Taxation regime
6. Uncertainty concerning disputed land claims
7. Uncertainty concerning what areas will be protected as wilderness, parks, or archaeological sites, etc…
8. Infrastructure
9. Socioeconomic agreements/community development conditions
10. Trade barriers
11. Political stability
12. Labour regulations/employment agreements and labour militancy/work disruptions
13. Quality of the geological database
14. Level of security
15. Availability of labour/skills

Scores for each are generated through companies' responses to a survey across jurisdictions. These are used to generate a PPI score through a ranking system, with the overall PPI normalised between 100 (most attractive) to 0 (least attractive). This measure is reliant on voluntary responses from companies. Therefore the number of responses per jurisdiction varies, and consequently the influence of each response on the scoring.

In 2012/2013 the PPI has been assessed for ninety seven jurisdictions, which capture most of influential mining countries. To provide greater detail Argentina, Australia, Canada and the United States are provided at a regional state level, with no overall country score provided. These account for forty five of the jurisdictions. Lack of data does not necessarily mean an absence of exploration and mining; it simply indicates that responses were not available for analysis.

To allow comparison with other production analysis the scores for the regions of Argentina, Australia, Canada and the United States have been averaged to produce and overall indicative score for the country. This results in PPI scores and ranking for fifty eight countries.[c]

Analysis of PPI

Figure 22 shows the geographical distribution of countries included in the PPI assessment, showing the countries' ranks by quartile. This shows that the coverage of this indicator is extensive across America

---

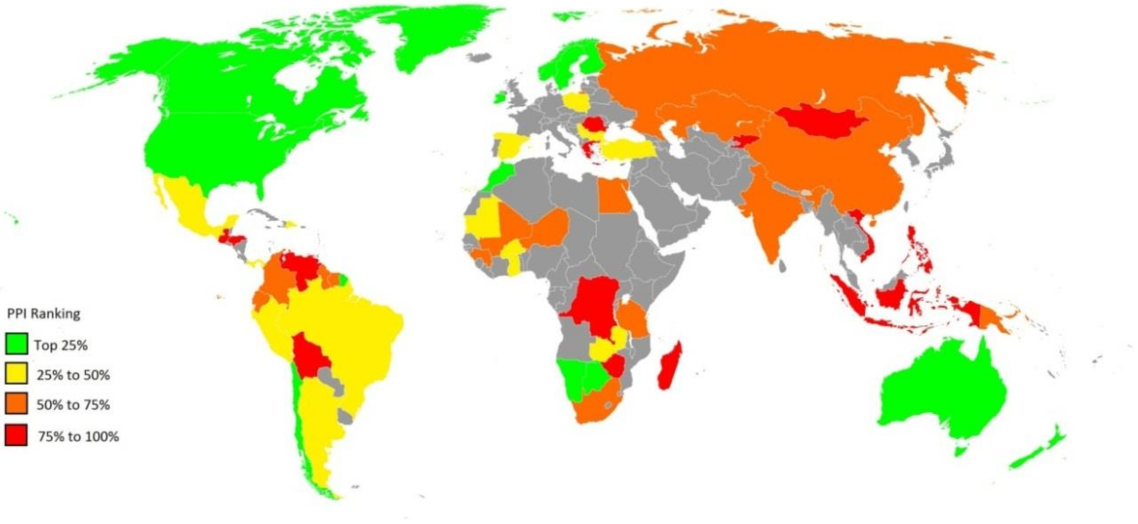
[a] Fraser Institute Survey of Mining Companies 2012-2012, Fraser Institute, 2013

[b] In addition Corruption and Growing (or lessening) uncertainty in mining policy and implementation were also surveyed, but not included in the overall PPI score

[c] A complete list is provided in PPI Scores (2012/2013)

and Asia. However, there are large areas of Africa and the Middle East which are not assessed. In total approximately 83% of production of all materials is covered, and around 93% of critical raw materials.

Figure 22: Geographical representation of PPI ranking based on quartile.



Source: Fraser Institute with own analysis.

The PPI shows that areas of the globe that are most attractive for developing mining are North America and Australia and a few countries in Africa, Europe and South America. Large areas of Asia are perceived as unattractive to the mining industry by this Index, including Russia, China, India, Kazakhstan and Mongolia. On a country basis Finland has the highest rating at 95.5 and Indonesia the lowest at 9.4.

Comparison can be made with the most significant producing counties (Table 21). Sixteen of the countries on this list are evaluated using the PPI, and all of the ten largest producing countries, which also have significant reserves of materials. These ten are clearly split into two halves; those with a comparatively high PPI (Canada, Chile, Australia, United States and Turkey) and those with a lower ranking (India, Russian Federation, China, South Africa, and Brazil). Whilst each of these low ranked countries had different factors influencing their ranking, common issues were identified as the legal system, land claims and trade barriers.

Table 21: PPI scores and ranks for 20 most important producing countries

Country	PPI	Ranking (Out of 58)	Country	PPI	Ranking (Out of 58)
Australia	66.1	9	Indonesia	9.4	58
Brazil	38.2	28	Italy	N/A	N/A
Canada	77.4	7	Japan	N/A	N/A
Chile	67.7	8	Kazakhstan	23.3	42
China	28.5	36	Mexico	57.3	16
DRC	12.3	55	Peru	42.0	25
France	N/A	N/A	Russia	28.1	37
Germany	N/A	N/A	South Africa	35.0	30
Greece	15.6	49	Turkey	49.7	20
India	21.1	43	USA	65.8	10

Source: Fraser Institute with own analysis.
N/A indicates no data, most likely due to lack of responses

Comparison with production of the critical raw materials shows that the greater part of surveyed production is accounted for by this indicator, with mainly small contributors to supply not included (Table 22). However, significant producers for indium (Japan, 10%, Ukraine, 6% and South Korea 4%) and gallium (Germany 10%) are omitted; in this case they are likely refiners of the metals rather than miners.

A weighted average PPI for each material has been calculated for comparative purposes, showing that those with the best composite PPI score are beryllium and lithium (Table 22). This is due to the influence of production in the USA for beryllium and in Chile and Australia for lithium. Those materials which score poorly include cobalt, gallium, tungsten, antimony, and magnesium. The lower score for cobalt is largely due to the influence of the DRC, whereas the others all have large components of supply from China.

Table 22: Analysis of critical raw materials and PPI using an indicative composite PPI value

Material	% Supply included in PPI countries	Indicative Average PPI*	Number of PPI Countries	Number of non-PPI Countries
Antimony	97%	28.4	11	4
Beryllium	98%	63.8	2	2
Borates	100%	53.9	8	1
Chromium	93%	32.9	14	7
Cobalt	94%	24.4	15	2
Coking coal	96%	39.6	15	5
Fluorspar	95%	35.3	13	7
Gallium	78%	28.1	3	5
Germanium	100%	46.4	5	5
Indium	70%	30.3	4	4
Lithium	99%	60.7	6	1
Magnesite	89%	31	14	7
Magnesium	96%	28.8	5	2
Natural Graphite	95%	30.1	9	4
Niobium	99%	40.9	3	5
PGMs	98%	33.8	5	1
Phosphate Rock	85%	43.8	21	14
REE	100%	32	5	1
Silicon	81%	40.2	5	2
Tungsten	95%	28.3	12	9

**Weighted according to country of production for indicative purposes only. For comparison Finland has the highest PPI rating (95.5) and Indonesia the lowest (9.4)*

Conclusions

Whilst the comparisons made above are useful, it should be restated that this Index measures the attractiveness of developing mining within a jurisdiction, rather than the risk associated with mining or related activities. Therefore it is perhaps best used as part of a forward looking analysis, along with factors such as prospective geological environment, to assess which materials have simplest potential for growth in supply. It does provide some useful information into current production as discussed above.

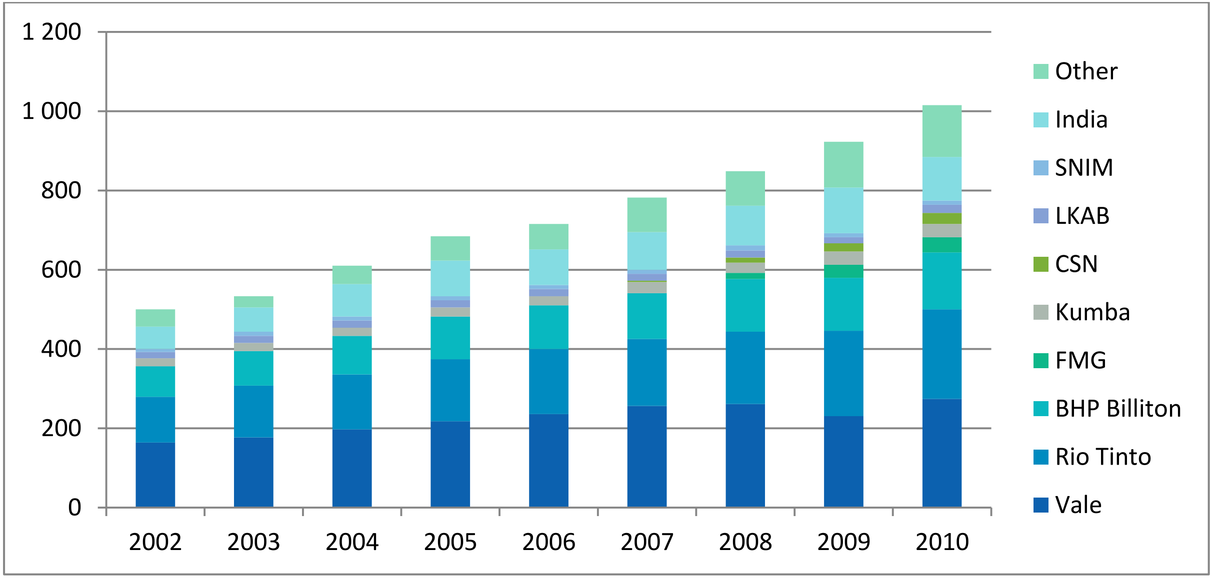
Overall conclusions on mining governance

Of the three mining governance schemes and measures discussed none has a broad enough coverage at present to be universally applied across all materials and countries. Therefore an overall assessment of potential influence on criticality is not possible. However, rather than being used in this way, these schemes give further insight of where supply is at most or least risk on a material and country level, or where exploration is most attractive. Therefore they are more relevant to inform actions targeting the sourcing of raw materials in the future as part of risk minimisation strategies, potentially this could be taken into account in the methodology. In the longer term, expansion of schemes could provide greater certainty and reliability over access, providing greater confidence in materials markets, thus reducing supply risk.

5.3.2 Corporate Concentration

As well as geographic concentration, as used in this analysis, corporate concentration can be an influencing factor on the supply risk of a raw material. This is 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. These have been some of the allegations levied against the “Big 3” iron ore producers (Vale, Rio Tinto and BHP Billiton), who account for approximately 60% of the world seaborne trade for iron ore (Figure 23). However, new players and Chinese diversification of sourcing have reduced the Big 3’s share of the market over time.

Figure 23: Corporate concentration of iron ore seaborne trade (million tonnes)



Source: Metalytics Presentation (June 2010), The Iron Ore Market: Relativity and Time

More widely, such collusive behaviour by firms and the resulting impact on prices are of concern even for important producing countries like China.[a] Although China is one of the largest producing and exporting countries of raw materials, it also relies heavily on imports. Therefore, in an environment in which companies and countries claim mining or cultivation (in the case of rubber) sites across the world, the potential sources of supply risk of a given raw material can be either located at the company level or at the country level. The reasoning is that there could be a risk of supply disruption for a given raw material, either due to market power of a company (or several companies) and its (their) possibility to influence supply and/or prices, or due to political instabilities in the country where the production is located, strategic behaviour of that country such as trade policy instruments or other political or regulatory reasons of the country.

Thus, this section discusses supply risk at the company level, i.e. corporate concentration. The aim of the on-going analysis is to provide the rationale, check for data availability, analyse and identify a possible quantification of the issue of corporate concentration so that it could be part of future refinements of the existing methodology. Due to the availability of data this section focusses on metals; however, a similar approach could be taken for other materials such as industrial minerals and biotic materials where data is available.

Approach

In competition policy (and especially merger control) market dominance in competition can be checked using several indices. The usual approach can be divided into two parts; firstly, the relevant market needs to be defined. That is often far from being an easy task. Subsequently, indices such as the

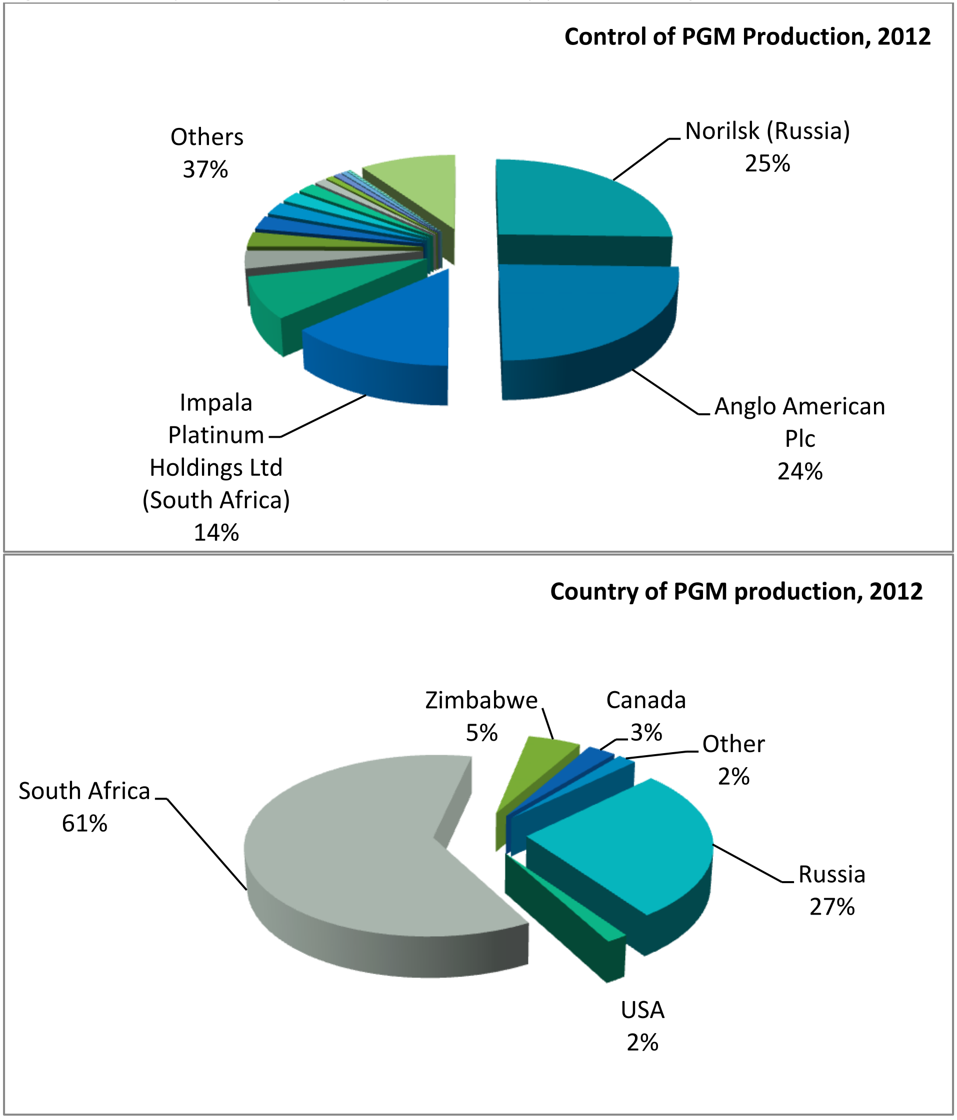
---

[a] Stiftung Wissenschaft und Politik, 2013, Fragmentation or Cooperation in Global Resource Governance? - A Comparative Analysis of the Raw Materials Strategies of the G20;(p.58)

Herfindahl-Hirschman-Index (HHI) or the concentration ratio (CR) are used as a first screening device for dominance. The HHI can be seen as a standard index of concentration and it is the most often used in anti-trust analysis.[a] 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 instead of percentage values 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.[b]

US Merger guidelines are especially clear in specifying thresholds for the HHI: "If the post-merger HHI is lower than 1,000 (low concentration), the merger will be approved. If the post-merger HHI is between 1,000 and 1,800 (moderate concentration), the merger is approved as long as it does not result in an increase in concentration of more than 100 points. If the post-merger HHI is more than 1,800 (high concentration) the merger is not challenged only if it increases concentration by less than 50 points. In all other cases, a merger raises significant competitive concerns and is likely to be investigated".[a] Nevertheless, these thresholds have been criticised as will be explained in more detail in the analysis part of the present chapter.

Figure 24: Comparison of company and country production of PGMs in 2012



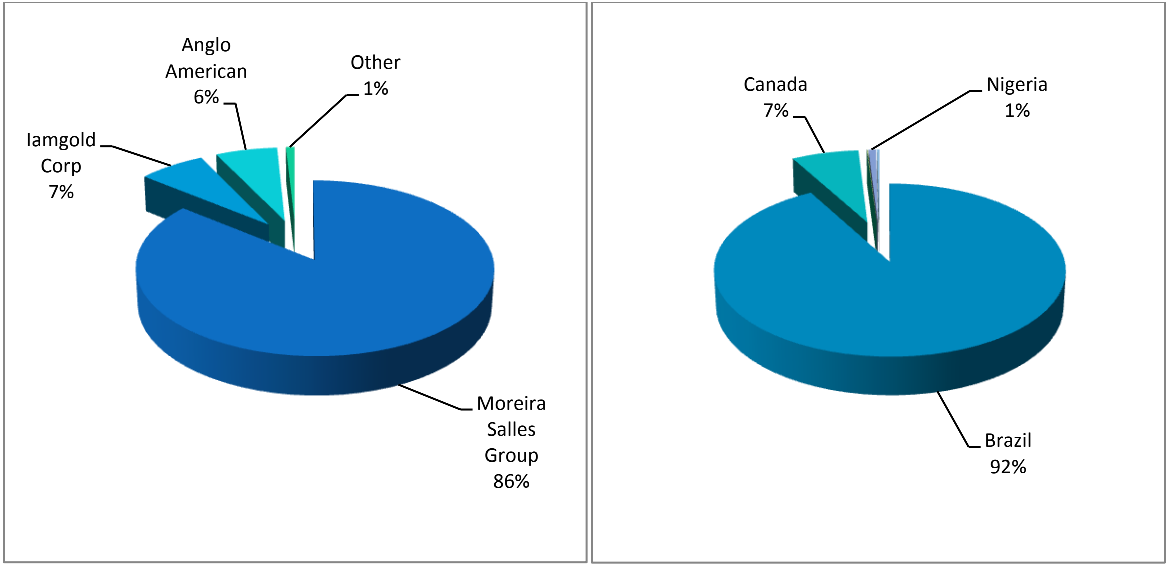
---

[a] Motta, M., 2007, Competition Policy: Theory and Practice. 7th Edition, New York (Cambridge University Press); p235

[b] The EU criticality methodology uses this Index as part of the supply risk measure, however it should be noted that it is modified to use country concentration

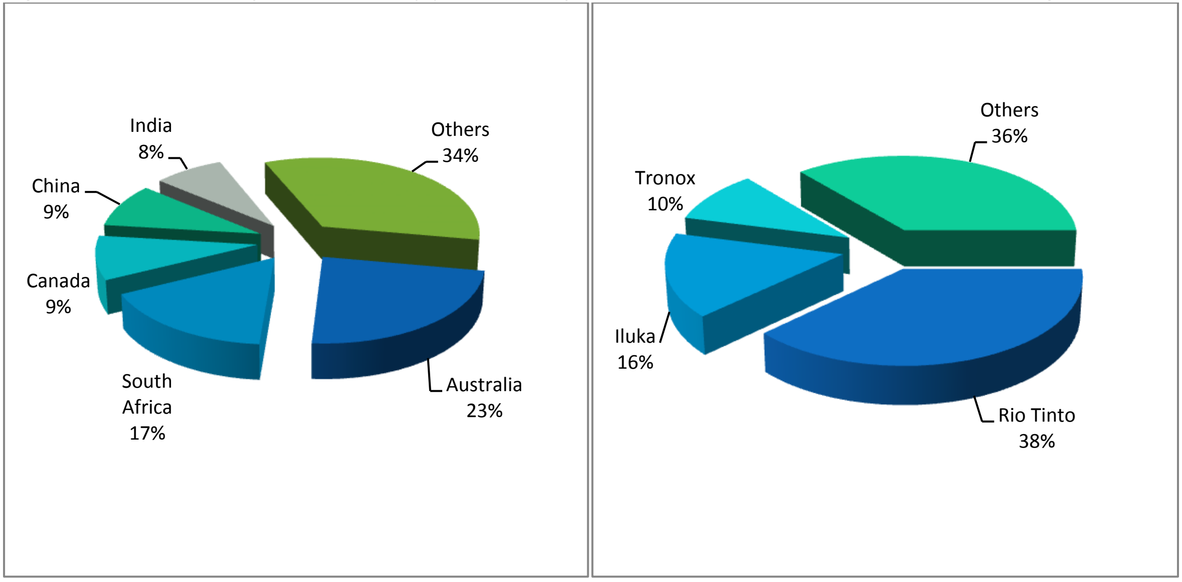
When looking at corporate production in place of country production, the broad picture for some raw materials becomes very different, for example the PGMs (Figure 24). While roughly 90% of the mining takes place in South Africa and Russia, the industry shows only a moderate concentration (HHI of 1637 in 2012); two companies, Norilsk and Anglo American, account for close to 50% of supply, with the remainder much more fragmented. By comparison, for other raw materials such as niobium, only a small change is seen. With a HHI of 7459 the niobium mining industry is a highly concentrated one; but slightly less concentrated than the mining where more than 90% takes place in Brazil.

Figure 25: Control of niobium production (2010) (left) vs. location of niobium mining (2010) (right)



Compared to many metals and minerals, titanium dioxide has relatively low geographic concentration and political risk. Australia and South Africa account for 40% of world mine production for titanium mineral concentrates, with the remaining 60% split between a dozen countries (Figure 26). However, corporate concentration is of greater concern. Notably, Rio Tinto - through its subsidiaries in South Africa (Richards Bay Minerals), Canada (Fer et Titane), Madagascar and Mozambique - has a near 40% market share for titanium feedstock. This example highlights that corporate concentration can be higher than country concentration.

Figure 26: Location (left side) and key producers of titanium dioxide mineral concentrates (right side) (%)



Source: USGS (2013), Mineral Commodity Summaries & Tronox (2012), Chemical and Agricultural Science Conference

Analysis

The analysis undertaken is structured as follows. As described above, using indices as screening devices for market concentration is only the second step after having defined the relevant market. Hence before investigating the concentration of the world market for a certain material, it should be checked if the material in question is really traded worldwide or if for instance material specific properties, freight costs or other factors constrain the geographic dimension of the market. Not every raw material is traded worldwide. So even though concentration worldwide is low, that picture might be misleading and real corporate concentration can be much tighter than the worldwide corporate concentration. If the material is not traded worldwide, the relevant market requires definition, which can be a challenging task.

Table 23: Development of Company Concentration between 2008 and 2012 for selected raw materials. The critical raw materials present have been underlined. Grey indicates where no or only poor data was available. Materials for which data quality is good to excellent are marked with a star.

Materials	2008	2009	2010	2011	2012
Aluminium*	866	887	1289	903	1665
Antimony		1399			
Bauxite*	1114	1127	1074	1104	
Borate		1399			
Chromium*	884	1085	1095	1975	
Cobalt*	2027	1044	963	1918	
Copper*	668	668	697	734	756
Gold	1503	1497	1516	1707	1926
Iron*	1127	1277	1047	1116	
Lithium*	1522	1574			
Manganese	1399	2710	1995	1944	
Molybdenum*	992	1238	1143	1225	1280
Nickel*	914	785	695	697	770
Niobium*	1399	7235	7459		
Palladium*	2895	3039	2567	2158	2354
Phosphate Rock	2248	2623	2796	2987	
Platinum*	1997	1910	1934	1812	1717
PGM*	1917	1983	1794	1690	1637
Potash*	1157	1482	1466	2063	
Silver*	795	711	663	631	819
Tantalum	3271				
Tin	3419	3412	3503	2893	
Titanium*	1530	1407	1476	1525	
Vanadium	3966	3966			

Source: Intierra Raw Materials Data with own calculations

Since some markets are characterised by large and infrequent orders made by a small number of buyers, market shares should be calculated over a long period like three to five years.[a] Hence, Table 23 shows the development of company concentration between 2008 and 2012 for twenty four selected raw materials. At present these are the materials available from Intierra's Raw Materials Data. As mentioned before, the Herfindahl-Hirschman-Index (HHI) can vary between 0 and 10,000 or between 0 and 1 if fractions instead of percentage values are used.

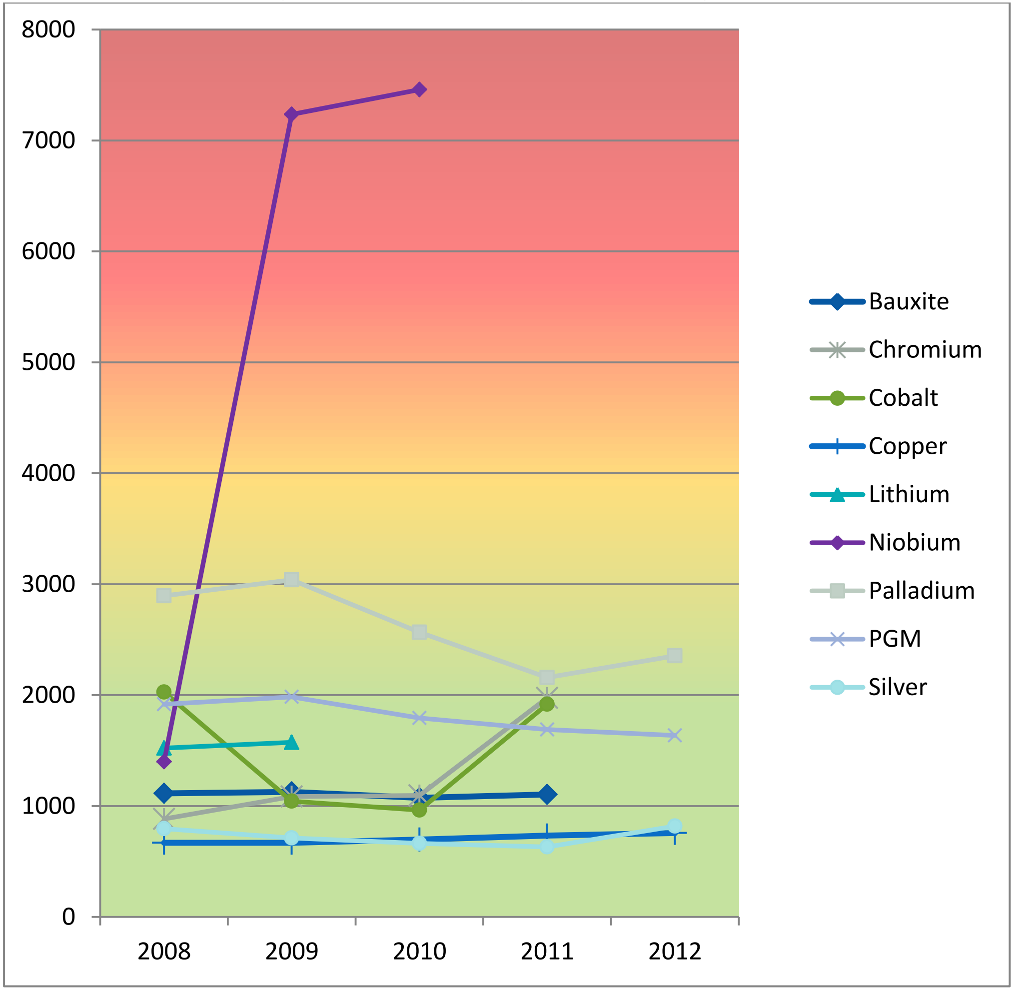
---

[a] Motta, M., 2007, Competition Policy: Theory and Practice. 7th Edition, New York (Cambridge University Press)

As data quality differs between materials, grey boxes indicate where no (or in some cases only data of very low quality, i.e. few minor companies) have been available. For instance for antimony, borates, lithium and vanadium the most recent data is for 2009. This is perhaps unsurprising since analogous data at a country level are poor for many materials.

Even though data on corporate concentration are available for these twenty four raw materials, data quality differs among them. Therefore in the following analysis the twenty four materials are divided into two groups: the first group gathering the sixteen materials with good to excellent data quality, i.e. almost all the market is known and almost or all production can be assigned to the different companies. These materials are marked with a star in Table 23. The development of corporate concentration as indicated by the HHI for selected raw materials is depicted in Figure 27.

Figure 27: Development of Company Concentration between 2008 and 2012 for critical raw materials and selected other materials for which data quality is excellent or good.



Source: Intierra Raw Materials Data with own calculations

Niobium and palladium appear the most influenced according to this measure. However, prior to closer examination of these materials it is worth discussing accepted assessment thresholds. As mentioned in the approach, the thresholds mentioned in US Merger Guidelines are well known. According to US Merger Guidelines, a HHI higher than 1800 (or 0.1800) indicates a high company concentration in the market (marked in orange). A moderate concentration (i.e. a HHI higher than 1000 and below 1800 (or 0.1000 and 0.1800) is marked yellow. Green colour coding shows a low concentration. Table 24 follows this colour coding.

Table 24: Development of company concentration between 2008 and 2012 for selected raw materials. The critical raw materials have been underlined. A high concentration is marked in orange, a moderate concentration in yellow. The thresholds are those by US Merger Guidelines. Grey indicates where no or only poor data was available.

	2008	2009	2010	2011	2012
Aluminium	866	887	1289	903	1665
Bauxite	1114	1127	1074	1104	
Chromium	884	1085	1095	1975	
Cobalt	2027	1044	963	1918	
Copper	668	668	697	734	756
Iron Ore	1127	1277	1047	1116	
Lithium	1522	1574			
Molybdenum	992	1238	1143	1225	1280
Nickel	914	785	695	697	770
Niobium	1399	7235	7459		
Palladium	2895	3039	2567	2158	2354
Platinum	1997	1910	1934	1812	1717
PGM	1917	1983	1794	1690	1637
Potash	1157	1482	1466	2063	
Silver	795	711	663	631	819
Titanium	1530	1407	1476	1525	

Source: Intierra Raw Materials Data with own calculations

As can be seen, while company concentration stays constant over time for some of the materials such as copper, nickel or silver, there are large movements for others such as the already mentioned critical materials niobium and palladium. Following US Merger guidelines for thresholds, the markets for chromium, cobalt, niobium, palladium and potash are considered highly concentrated in terms of corporate concentration using the most recent data. With the exception of potash, these are in the list of critical raw materials. In the case of the critical material lithium, moderate corporate concentration is seen up to 2009 with more recent data unavailable. For PGMs which are also in the list of critical raw materials, moderate corporate concentration is seen, which has declined between 2008 and 2012; although palladium and platinum (two individual PGMs) experience higher scores, indicating the differences in supply for the individual materials compared to the whole group.

The thresholds set by US Merger Guidelines have been criticised as being strict. Therefore, according to US Federal Trade Commission and the U.S. Department of Justice state statistics for the years 1999-2003, higher HHI values are used for most cases where mergers are challenged.[a] In these cases an HHI below 2000 is indicative of a market with low concentration, between 2000 and 2400 a moderate concentration, and an HHI of 2500 or higher indicates a high company concentration. When these less strict thresholds are applied, the movement for niobium and palladium is still clear (Table 25). While niobium became a highly concentrated market after 2008 (Figure 28), company concentration for palladium showed a decreasing trend from 2008 to 2012, going from highly to moderately concentrated over the years analysed.

---

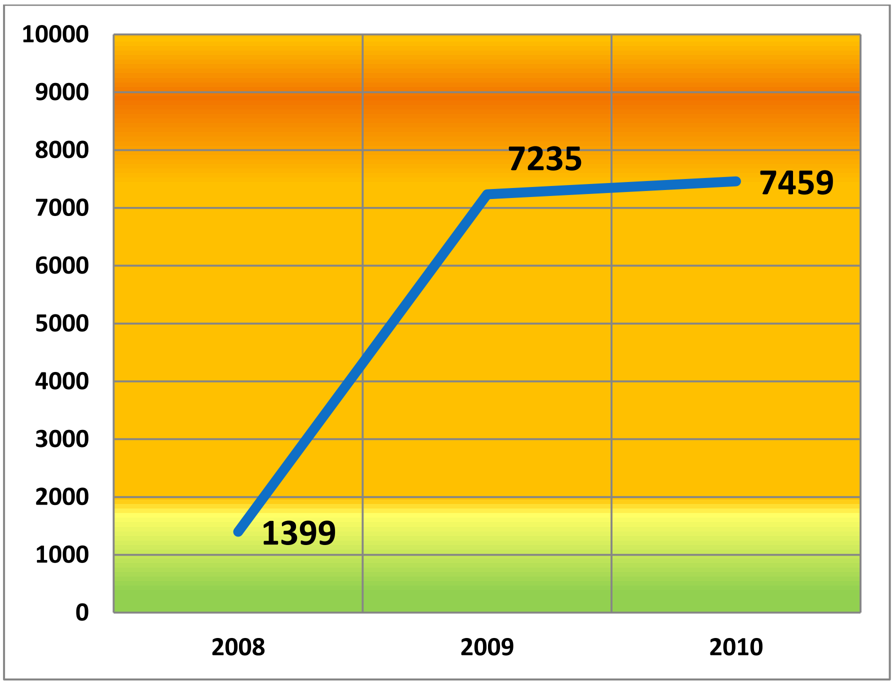
[a] http://www.justice.gov/atr/public/201898.htm, accessed 22/09/2013

Table 25: Analysis using lower HHI thresholds. A high concentration is marked in orange, a moderate concentration in yellow and a low concentration in green.

	2008	2009	2010	2011	2012
Aluminium	866	887	1289	903	1665
Bauxite	1114	1127	1074	1104	
Chromium	884	1085	1095	1975	
Cobalt	2027	1044	963	1918	
Copper	668	668	697	734	756
Iron	1127	1277	1047	1116	
Lithium	1522	1574			
Molybdenum	992	1238	1143	1225	1280
Nickel	914	785	695	697	770
Niobium	1399	7235	7459		
Palladium	2895	3039	2567	2158	2354
Platinum	1997	1910	1934	1812	1717
PGM	1917	1983	1794	1690	1637
Potash	1157	1482	1466	2063	
Silver	795	711	663	631	819
Titanium	1530	1407	1476	1525	

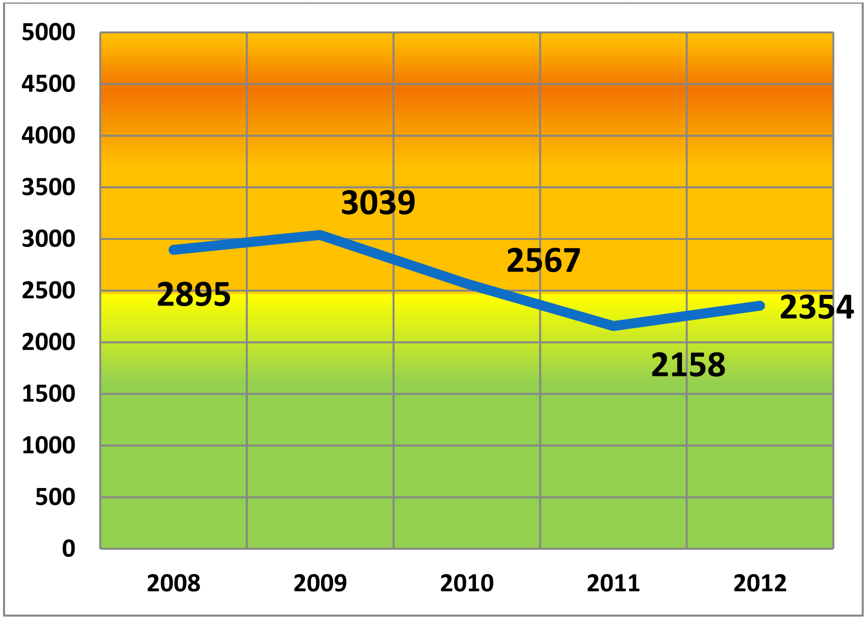
Source: Intierra Raw Materials Data with own calculations

Figure 28: Increasing Company Concentration (HHI) for Niobium between 2008 and 2010. Colour coding of the background marks the level of concentration ranging from low concentration (green) over moderate concentration (yellow) to high concentration (orange). The thresholds follow US Merger Guidelines.



Source: Intierra Raw Materials Data with own calculations

Figure 29: Decrease of corporate concentration at the palladium market between 2008 and 2012.



Source: Intierra Raw Materials Data with own calculations

Similar analysis has been performed for the other materials covered by Intierra's Raw Materials Data that have lower quality data (Table 26 & Table 27). For each year, 2008 until 2012, two different HHI values have been calculated for each material, i.e. a lower and an upper bound. This is due to differing data quality and availability. For some materials, less than 100% of the total world production could be assigned to the identified companies in some years. Where this is the case, in the calculation of the "upper bound" the remaining percentage share of "other (unknown) companies" has been treated as if it would belong to one single company. This is similar to production data at the country level where in some cases there also appears the category "other" for other production countries. However, as this may lead to an over-estimation, a lower bound is calculated leaving the unknown part aside, and hence assuming the distribution of the whole market is the same as the distribution of the known market.

Table 26: Development of company concentration between 2008 and 2012 for selected raw materials. The critical raw materials have been underlined. A high concentration is marked in orange, a moderate concentration in yellow and a low concentration in green. The thresholds are those by US Merger Guidelines. Grey indicates where no or only poor data was available.

Materials	**HHI 2008**		**HHI 2009**		**HHI 2010**		**HHI 2011**		**HHI 2012**	
	lower bound	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**
Antimony			151	1399						
Borate			151	1399						
Gold	282	1503	246	1497	251	1516	221	1707	200	1926
Manganese	151	1399	199	2710	352	1995	360	1944		
Phosphate Rock	411	2248	288	2623	317	2796	296	2987		
Tantalum	2037	3271								
Tin	643	3419	513	3412	483	3503	542	2893		
Vanadium	959	3966	639	3966						

Source: Intierra Raw Materials Data with own calculations

Colour coding of Table 26 follows the thresholds of US Merger Guidelines, while in Table 27 the more lax thresholds have been applied. As can be seen in both tables, data quality is such that in the case of some of the materials it is more difficult to draw firm conclusions based alone on the HHI values. In these cases not enough of the production can be assigned to different companies for the analysed years. This is the case for phosphate rock, tin and vanadium (Table 27). The CRMs antimony and borates have markets with low concentration; though only one data point is available for 2009, and there is a large uncertainty with phosphate rock. Of the other materials, gold and manganese have consistently seen a low concentrated market. Tantalum has been a moderate to high concentrated market in 2008, as the boundaries in Table 27 indicate. Further data would be necessary to draw conclusions, such as that ~44% of the production in 2008 came from one single company and that three companies divide roughly 60% of the market between them. Unfortunately, since only 65% of the production can be assigned to companies, it is unclear how many companies divide the rest of the market between them. Further investigations would be necessary.

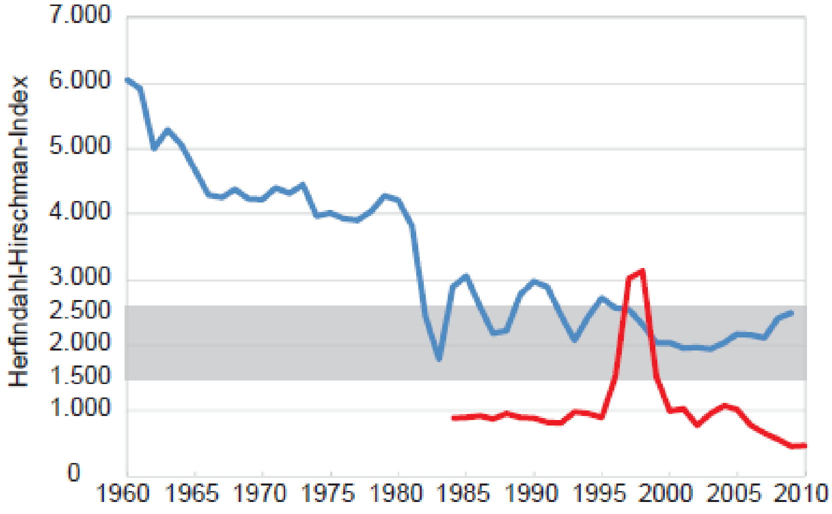
Table 27: Development of Company Concentration between 2008 and 2012 for selected raw materials. The critical raw materials have been underlined. A high concentration is marked in orange, a moderate concentration in yellow and a low concentration in green. The more lax thresholds have been applied. Grey indicates where no or only poor data was available.

Materials	**HHI_2008**		**HHI_2009**		**HHI_2010**		**HHI_2011**		**HHI_2012**	
	lower bound	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**
Antimony			151	1399						
Borate			151	1399						
Gold	282	1503	246	1497	251	1516	221	1707	200	1926
Manganese	151	1399	199	2710	352	1995	360	1944		
Phosphate Rock	411	2248	288	2623	317	2796	296	2987		
Tantalum	2037	3271								
Tin	643	3419	513	3412	483	3503	542	2893		
Vanadium	959	3966	639	3966						

Source: Intierra Raw Materials Data with own calculations

Comparison of country and corporate concentration can be made, with both changing considerably over time as shown in Figure 30 and Figure 31 for molybdenum and cobalt respectively.

Figure 30: Mining Production of molybdenum between 1960 and 2010. The red line shows corporate concentration, the blue one concentration at the country level.

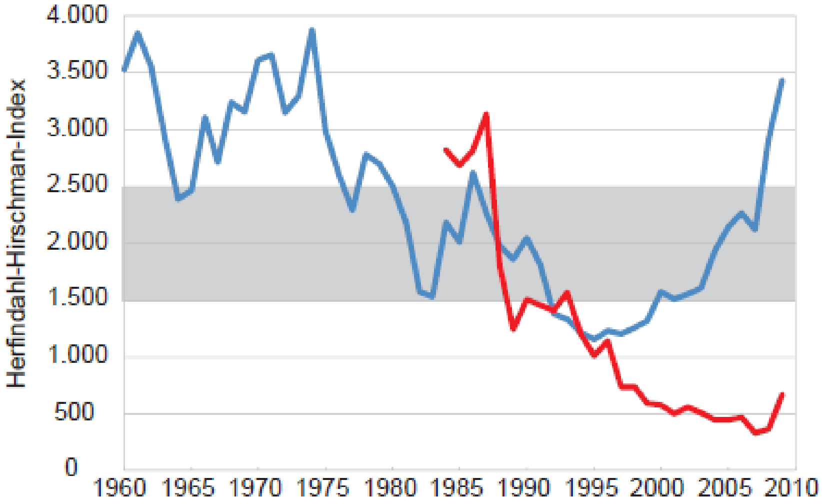


Source: DERA (2012) Angebotskonzentration bei Metallen und Industriemineralen – Potenzielle Preis- und Lieferrisiken.

Corporate concentration in the molybdenum market has generally been lower than the country concentration. However, a spike is seen in the company concentration in the late 1990s and early 2000s reaching a level that is considered a high concentration; even when applying the more lax thresholds mentioned above, it had been significantly decreasing afterwards. More recently, the molybdenum market is a low to moderate concentrated one, both in terms of corporate concentration and at country concentration. Molybdenum is not on the list of critical raw materials derived in the quantitative analysis.

Unlike molybdenum, cobalt is a critical raw material in the current analysis. As can be seen in Figure 31, the cobalt market had been considered a highly concentrated one in the mid-1980s, with the corporate concentration exceeding the company concentration. This declined by both measures until the late 1990s. After this point corporate concentration continued declining, while county concentration significantly rose again. This might not be surprising as over half of world cobalt production is now mined in the DRC.

Figure 31: Mining production of cobalt between 1960 and 2010. The red line shows corporate concentration the blue one concentration at the country level.



Source: DERA (2012) Angebotskonzentration bei Metallen und Industriemineralen – Potenzielle Preis- und Lieferrisiken.

Many of the materials identified in this analysis are used in steel industry, i.e. chromium, iron ore, manganese, molybdenum, niobium and vanadium. The markets for chromium, iron ore, and molybdenum are considered as low to moderately concentrated markets (Table 24 & Table 25). As described above and shown in, molybdenum has been a highly concentrated market. Niobium is a highly concentrated market not only in terms of corporate concentration but also when it comes to concentration at the country level. Data for manganese and vanadium are of lower quality as described above. Nevertheless conclusions are possible. The market for manganese can be considered as having low concentration. In the case of vanadium, a closer look is necessary. In 2008 43.86 % of the production came from one single company and three companies roughly split 60% of the market between them. Thus the market seems to be quite concentrated. Unfortunately, since only 65% of the production can be assigned to companies, it is unclear how many companies divide the rest of the market between. Hence it can be concluded that out of the materials used in steel production mentioned only niobium and vanadium are potentially of concern when it comes to corporate concentration.

Conclusions

As shown above the analysis of corporate concentration shows interesting insights. As described above, analogous data for company supply to country supply is available for several materials. Thus it is possible to not only check if the mining for a certain raw material is concentrated in one or few countries but also if mining companies are concentrated and thus they can be expected to exercise significant market power. The analysis above shows there are some similarities between the metals experiencing high supply risk (and therefore considered critical) and those with a high company concentration. This is highlighted by niobium and PGMs to a certain extent. However, other critical raw materials such as borate and antimony experience low company concentrations, indicating a lower supply risk using this measure.

This analysis also demonstrates that the issue of company concentration could be quantified in a future studies, and may add richness to the work. However, more data covering also the other raw materials that are part of the present study would be necessary in order to conduct the full analysis. The data exists for many, but it would be necessary to gather the data from the different data sources (some of them paid ones). That data gathering would be out of the scope of the present study. Besides, it can be easily concluded that the materials for which data quality is not that excellent or more difficult to get are the ones being more interesting in the sense of that one might expect those markets to be less transparent. A numerical method for this inclusion in the methodology is outlined in Annex H.

5.4 Refining Stage

5.4.1 Comparing Metal and Mine Production

Though mine production was and remains the primary focus of the analysis concerning supply risk, there are several raw materials in the scope of the study that are best analysed at the refining stage. This is true mostly for by-product metals such as indium and gallium. However, there are cases where the Ad-hoc working group saw/sees it as warranted to examine not only the mining stage but also the smelting and/or refining stages of the supply of raw materials. In this section, the consequences of these choices are highlighted based on examples. First, the cases already considered in the current analysis are examined: these are bauxite/aluminium and silica sand/silicon[a]. Then, some examples not included in the scope of the analysis are discussed.

Most bauxite is converted to aluminium and both stages are already considered in the present study. In both cases, the score for economic importance is very high but they are not classified as “critical” on the basis of their comparatively low supply risk scores. Figure 32 shows the geographical distribution of production of bauxite (the raw material for aluminium) and aluminium metal.

Figure 32: Geographical distribution of production of bauxite (=“Mine”) and aluminium (=“Refinery”)

Data for bauxite were taken from IntierraRMG’s Raw Materials Data and for aluminium from World Mining Data 2012.

Inspection of the charts reveals that aluminium refining is spread across more countries than bauxite mining is, and that the countries involved in mining and refining are very different[b]. As a result[c], the supply risk scores obtained for bauxite and aluminium are different, but both are below the threshold set for the supply risk dimension of the critical region. Therefore, considering both stages separately leads to a richer picture for bauxite/ aluminium but does not make a significant difference regarding its classification as “critical” or “non-critical”.

The case of silica sand and silicon metal is different because most bauxite is used for the production of aluminium; but this is not true for silicon metal and its required raw material, high-purity quartz (SiO_2). Therefore, the analysis for silicon metal is more specialized than that for the more broadly defined raw material (silica sand) considered with all its end uses and different grades.[d] In the case of silicon metal,

---

[a] Note that the “ore” is in both cases a valuable product on its own right (industrial minerals).
[b] Notice that the necessary conversion of bauxite to aluminium oxide is not shown here.
[c] Other important differences are in the substitutability assessment and recycling rates.
[d] Silica as high purity quartz or quartzite is used as the raw material for silicon metal production, but no systematic data

this differentiation is justified on the grounds that the markets do not significantly influence each other. The end use structures of the more narrowly (silicon metal) and the more broadly (silica sand) defined raw materials are different leading to different assessments of their economic importance. A smaller, more specialized market is one that can more easily be in fewer hands (more concentrated). Considering silicon metal separately results in a significantly higher supply risk score compared to silica sand, bringing silicon metal into the list of critical raw materials.[a]

In addition, there are rare materials where ore and metal production could be considered at different stages in the supply chain but have not been so far. Three examples are examined here: manganese, nickel and zinc.

The geographical distribution of manganese mine and refinery production is shown in Figure 33. A glance at the two charts shows that not only do mining and refining occur in different countries but that the refinery production is significantly more concentrated than the mining production (possibly linked to the energy requirements for metallurgical processing). Following the logic of the criticality methodology, this should lead to a higher supply risk score[b]. The supply risk scores for manganese (mine production) are 0.4 and 0.5 based on governance and environmental performance, respectively. However, if the analysis is carried out at the refinery stage, these scores become 1.5 for both measures, i.e. above the respective thresholds for supply risk. Therefore, it is evident that the stage in the supply chain at which the analysis is performed can dramatically change the conclusions reached.

Figure 33: Geographical distribution of production of manganese both at the mine and refinery stages

Data from World Mining Data 2012 and USGS Minerals Yearbook 2011.

The case of nickel also shows a strong geographical shift between the mine and refinery stages in the nickel supply chain (Figure 34). However, there is no apparent increase in the concentration of supply. Thus, the main change in the indicators calculated comes from the different scores (governance and environmental performance) attached to the producing countries. The supply risk score for nickel is calculated as 0.2 (both for WGI and EPI) for the mining stage and the analysis yields values of 0.3 for both measures. Therefore, in the case of nickel, the supply risk scores calculated at the mining and refining stages of the supply chain are essentially identical.

---

is available on high-purity quartz and quartzite mining and production.

[a] Notice that the scores for silicon metal and silica sand are both above the threshold for economic importance. Therefore, the differentiation in “critical” and “non-critical” depends on their different scores for supply risk.

[b] Assuming recycling rate and substitutability assessment both remain equal, which is true in this case.

Figure 34: Geographical distribution of production of nickel both at the mine and refinery stages

Data from IntierraRMG's Raw Materials Data and USGS Minerals Yearbook 2011.

The final case considered here is that of zinc (Figure 35). Here, the leading producer at the mine stage (China) is also the leading producer at the smelter stage; major geographical shifts only occur on comparatively small producers. As a result, the supply risk score for zinc barely differs when calculated at the mining and smelting stages.

Figure 35: Geographical distribution of production of zinc both at the mine and smelter stages

Data from USGS Minerals Yearbook 2011.

Combining these five examples, we can conclude that assessing the supply risk scores at the different stages of the supply chain can, but does not always, lead to different results. Assuming the other elements in the supply risk assessment remain (nearly) the same, a major shift (upward or downward) in the concentration of production must occur between supply chain stages to merit a significantly different supply risk score. This is not the case for zinc, nickel and aluminium, but it is true for manganese. In the latter case the change is so significant that the raw material would be classified as "critical" if evaluated at the refining stage.

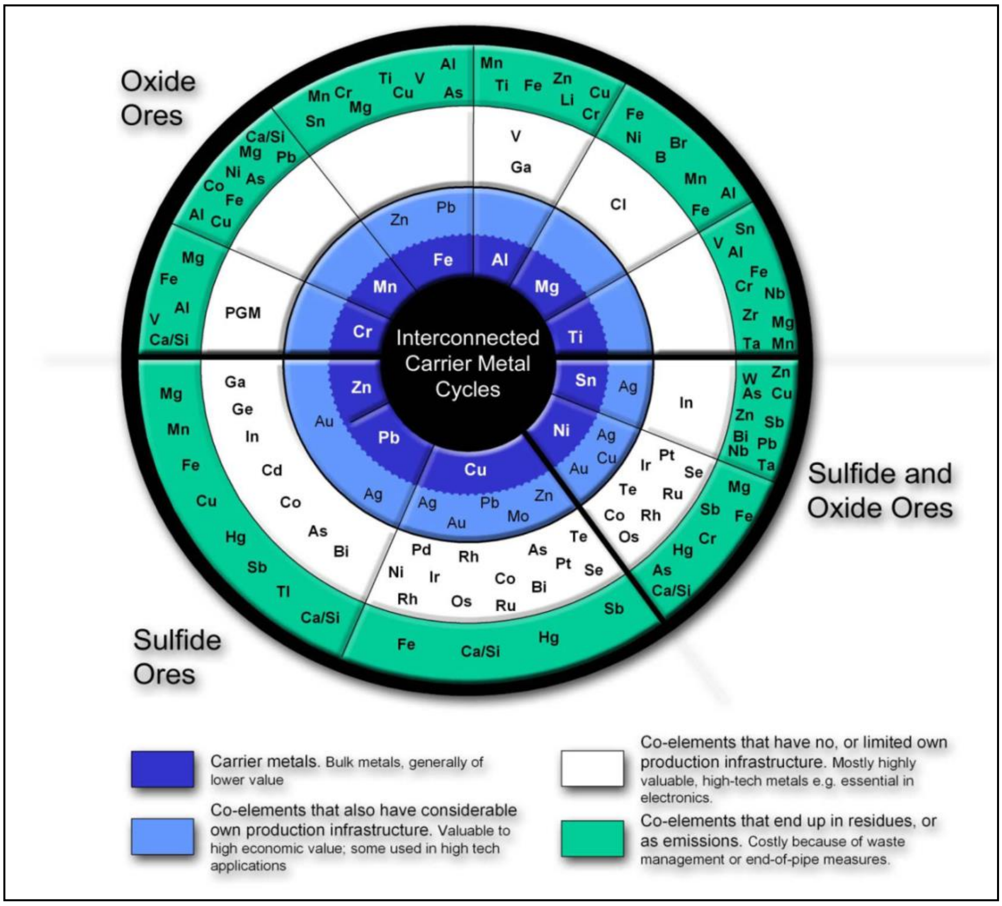
If the analysis must be split into smaller markets at the later supply chain stages (as is the case for silica sand and silicon metal), it is intuitive that the smaller market will tend to be more concentrated than the larger market, leading to a higher supply risk score. Also, if the distribution of uses is markedly different (as it probably is), both the score of economic importance and the substitutability index (used in the supply risk assessment) may vary strongly, potentially leading to markedly different criticality assessments. Therefore careful consideration and classification is required if the scope of the criticality assessment is extended to cover certain subsidiary raw materials.

5.4.2 By-Product Dynamics

The results and analysis of EU critical raw materials study highlight that several of the materials identified as critical are by-products of base metals. These include cobalt, gallium, germanium, indium, and even REEs and PGMs to some extent.

The market dynamics and economics of production of by-products are often quite different to primary products, since their production is largely driven by demand for the primary metal. Figure 36 illustrates the relationships between the major base metals and the associated by-product and co-product metals.

Figure 36: By-product and co-product metals



Source: Reuter et al. (2005): The Metrics of Material and Metal Ecology, Harmonizing the resource, technology and environmental cycles

For by-product metals, the number of players is typically lower than for the other metals because of the size of these markets and the economies of scale available. However, the markets for these by-product metals are often more elastic than the criticality analyses assume, as refiners can adjust their processes and respond to higher prices; there are significant quantities of by-product metals not currently being recovered.

This section draws upon the detailed data and information collected by a report commissioned by the International Study Groups on the by-products of copper, nickel, lead and zinc[a], the base metals from which the majority of these by-products are currently recovered. Additional analysis and reasoning has been conducted on the link between by-product status and raw materials criticality. Three outlooks on how by-product status could influence raw material criticality are discussed below. These are linked risk with base metal sources, percentage recovery of available by-product, and revenues of by-product relative to the main product.

---

[a] ILZSG (2012), Study of the By-Products of Copper, Nickel, Lead and Zinc; Oakdene Hollins

Linked risk with base metal sources
For the majority of the by-product metals, data are available on the sources of production, split between each of the host metals (Table 28). It could be imagined that by-production risk could be directly included through apportioning the supply risks of each of the base metals according to their share of supply of the by-product metal. However, this would be quite simplistic and also misleading.

The first reason for this is geology. For most by-product metals the presence and concentration within the host ore varies considerably within the deposit type. And even within the same class of ore body, concentrations may vary considerably. For example, for the copper by-products, each of these tends to be produced from different types of ore:

- Molybdenum and rhenium primarily from porphyry deposits, such as in Chile
- Cobalt from sedimentary deposits such as the Central African Copperbelt
- Selenium and tellurium typically from various copper sulphide deposits.

In addition, the concentration of many by-product metals, such as gallium, in base-metal ore bodies is not well or widely characterised, making this difficult to assess.

The second reason for this concerns refining. For some by-product metals, it is not uncommon for production to be located in distinctly different locations to where they are mined, meaning that the supply risks for refined by-products may be considerably different to that of the mining of the base metals. Major refiners will commonly source feedstock from various locations from around the world, and by-product content is just one factor out of many for consideration in these types of strategic decisions. In addition the refining process may also affect the economics of their recovery.

Recovery of the percentage available
For a number of the by-product metals, relatively detailed information is available on current and potential recovery rates. Usually two factors are of relevance: whether a particular refinery is recovering that by-product at all, and the efficiency at which this occurs. The first of these is a more strategic decision, as described above. The second is more of a technical decision, and reflects the trade-offs between recovering one metal over another and is intrinsically linked to the specific hydro- or pyro-metallurgical methods employed. The following estimates of recovery rates are from specific studies:[a]

- Cobalt: 75%-90% recovery efficiency from nickel and copper respectively
- Gallium: only 10% of alumina refineries worldwide are thought to recovery gallium[b]
- Germanium: ≈12% of germanium contained in zinc recovered by refineries outside China
- Indium: 25%-30% of indium contained in zinc recovered by refineries outside China and CIS
- Molybdenum: 70%-80% recovery efficiency from copper ores are typical
- Rhenium: ≈75% recovery of rhenium contained in copper-molybdenum deposits
- Selenium: 55%-65% selenium recovery from maximum potential in copper anode slimes
- Tellurium: 30%-40% tellurium recovery from maximum potential in copper anode slimes.

For precious metals, recovery rates for gold, silver and platinum group metals typically exceed 95% for a combined copper and lead refinery (such as at Dowa or Umicore), and exceed 99% for a copper smelter (such as at Boliden, Xstrata or Aurubis).[c] For primary palladium production, recovery efficiency can be as low as 40%-60% due to the very low concentrations within these ores.[d] For hafnium, recovery rates from zircon are low, due to the fact that it is only economically recovered from nuclear grade zirconium metal where hafnium is an undesirable impurity.[e] Further discussion can be found in an INSEAD working paper[f]; however, the estimates contained in that report differ wildly to those quoted above. Review of the methodology and data quality in the INSEAD report suggests a less detailed and robust approach. It has attempted to estimate potential by-production versus actual production by comparing concentration

---

[a] For further information see ILZSG (2012), Study of the By-Products of Copper, Nickel, Lead and Zinc; Oakdene Hollins
[b] See Indium Corporation (April 2010), Indium, gallium & germanium: supply & price outlook; ICA Rare Metals Symposium
[c] OECD (Oct 2010), Global Forum on Environment focussing on Sustainable Materials Management
[d] For further information see ILZSG (2012), Study of the By-Products of Copper, Nickel, Lead and Zinc
[e] Lipmann Walton & Co (Oct 2012), Hafnium Supply-Demand – MMTA – Brief Metal Statistics
[f] INSEAD (2011), Rare and Critical Metals as By-products and the Implications for Future Supply, Working Paper

in ore bodies. However, the methodology is considered to be too generic, as it has applied specific geological estimates of ore composition to a much broader set of deposits, leading to misleading and inaccurate results.

Table 28: Summary of by-product sources, recovery efficiencies and contributions to refinery revenues. Critical materials have been underlined

By-Product Metal	Sources of Production	Share of Production	Recovery Efficiencies	Max. Share of Total Revenues	Example Refinery
Cobalt	Nickel	55%	75%-90%	≈15%	at Sherritt, Canada
	Copper	35%		≈15%	at Katanga, DR Congo
	Primary	10%	-	-	
Gallium	Alumina	90%	10%	≈4%	at AOS Ingal, Germany
	Zinc	10%	-	-	
Germanium	Zinc	75%	≈12%	≈2%	at Teck Trail, Canada
	Coal	25%	-	-	
Gold	Primary	≈90%	-	-	
	Copper	≈10%	>99%	≈20%	at Kennecott, USA
Hafnium	Zircon	100%	Low	<1%	worldwide market size
Indium	Zinc	100%	25%-30%	≈3%	at Teck Trail, Canada
Molybdenum	Copper	50%	70%-80%	≈20%	at FCX, North America
	Primary	50%	-	-	
Palladium	Platinum	60%	40%-60%	≈15%	In South Africa
	Nickel	40%	-	≈15%	at Norilsk, Russia
Platinum	Nickel	15%	-	≈10%	at Norilsk, Russia
Rare earths	Iron	45%	-	-	at Baosteel, China
	Primary	55%	-	-	
Rhenium	Copper	100%	≈75%	≈0.3%	at KGHM, Poland
Scandium	Tungsten, tin, titanium slags	60%	-	-	
	Phosphates	30%	-	-	
	Rare earths	10%	-	-	
Selenium	Copper	90%	55%-65%	≈0.2%	at Boliden, Sweden
	Lead	10%	-	-	
Silver	Lead-Zinc	35%	>95%	≈45%	at Teck Trail, Canada
	Primary	30%	-	-	
	Copper	23%	>99%	≈25%	at KGHM, Poland
	Gold	12%	-	-	
Tantalum	Tin	20%	N/A	≈10%	in DR Congo
Tellurium	Copper	90%	30%-40%	≈0.2%	at Boliden, Sweden
	Lead	10%	-	≈2%	at Port Pirie, Australia
Vanadium	Steel slags	75%	-	-	
	Primary	25%	-	-	

Source: ILZSG (2012), Study of the By-Products of Copper, Nickel, Lead and Zinc; additional references & Oakdene Hollins analysis

Revenues of by-product relative to the main product

An analysis of the revenue mix of base metal refineries gives a picture of the relative economic incentives for recovering specific by-product metals. This type of analysis will be specific to a given refinery, and will vary according to the particular ore or feedstock processed. It will also depend upon current metals prices, which will fluctuate considerably year-to-year. These fluctuations will in turn influence technical decisions relating to recovery trade-offs and efficiencies, and therefore year-to-year production.

In terms of data availability, metals price data is relatively widely accessible for all the base metals, and the majority of by-product metals. Operational data for annual metals production at specific refineries is often published within company annual reports, although the level of detail may vary considerably between the companies concerned. For the sake of brevity and commercial sensitivity, production figures for the entire product mix may not be published (including the by-products), although estimates may be available from other sources.

Case Study: Does by-product status raise or lower supply risk?

The research conducted has highlighted examples where by-product status may both raise and lower the supply risk of specific raw materials. Case studies are provided here for a number of the by-product metals to illustrate these points:

Gallium: Quicker responses to price rises

Gallium has been a very dynamic market in the last few years. Its supply has experienced a step-change, with world primary production trebling in just two years between 2009 and 2011. This very fast-paced ramp-up in world capacity has been driven by forecasts for strong increases in demand, driven by the uptake of LED lighting technologies.

Gallium is recoverable from most bauxite ores. With the installation cost of a recovery circuit at approximately €20m it is a relatively short-term investment decisions, meaning that supply can respond to rising demand and prices within just a couple of years, rather than the 5-10 years needed to develop a greenfield mine. And with a market size of 80 tonnes back in 2009, the addition of just a few more refiners can have a large impact on total world supply.

Indium: Adds complexity to refining

The major source of world's indium is as a by-product of zinc refining. However, significant indium content is limited to only around 40% of the world's zinc concentrates. Therefore, in order to recover indium, zinc refiners must implement a strategic decision to procure right zinc concentrates, so that the average indium content justifies its recovery.

Much of these indium containing-zinc concentrates originate from Peru and Bolivia (with relatively high political risk). These concentrates often contain higher levels of contaminants such as arsenic and cadmium, which can mean that they are more difficult to process. Traditional zinc refineries are often reluctant to engage in a small and volatile market, where additional complexity is added to the process, even if attractive investment returns are possible.

Cobalt: Steady base load in supply

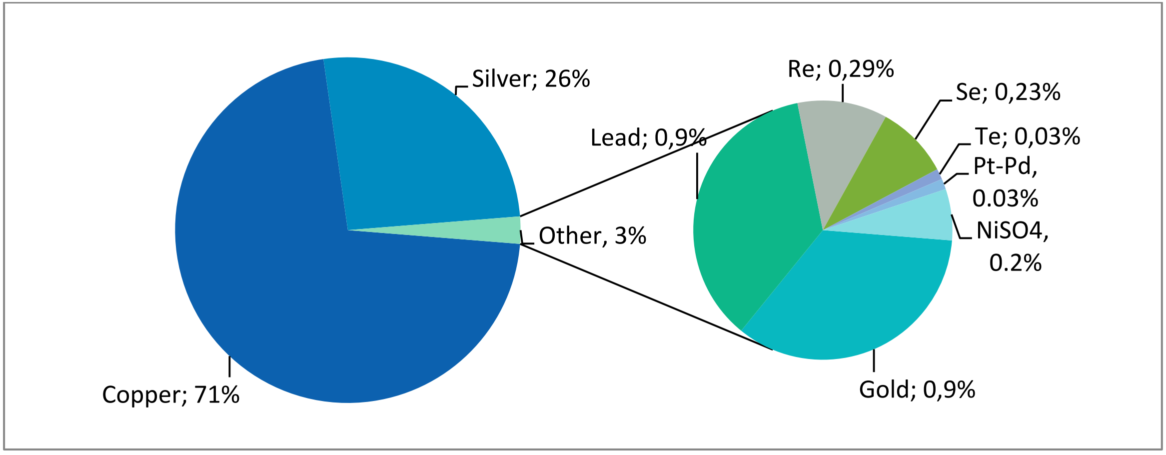
For cobalt, world supply is diversified between that refined in the nickel and copper industries, and that originating from primary cobalt operations. The fact that cobalt is a valuable by-product from both nickel and copper means that is routinely recovered, providing a steady-base load of supply.

The project pipeline for cobalt projects indicates that 90,000 tonnes of additional mine production may become available by between 2010 and 2015, as result of numerous new mines and planned expansions. This is driven by the sustained demand and high prices witnessed for nickel and copper and could push the market into oversupply. The by-product refiners will be to some extent insulated from falling prices, with the primary cobalt producers likely to be much more exposed.

References: See EC JRC IET (2011), Critical Metals in Strategic Energy Technologies; ILZSG (2012), Study of the By-Products of Copper, Nickel, Lead and Zinc; & USGS Commodity Summaries and Yearbooks

A summary of collated examples can be found in Table 28. The method is illustrated with the example of the KGHM Głogów Refinery in Poland. For this refinery copper is the main product, representing an estimated 71% out of over $5bn of revenues for 2011, Figure 37. Silver is a valuable co-product because of the specific type of ore processed. Sales of silver account for approximately one quarter of total revenues. A further ten by-products are produced by the refinery (including acid and slag products), sales of which are estimated at approximately 2.5% of total refinery revenue. Of particular note is rhenium, which only represents 0.3% of sales revenue (approximately $15m), even though KGHM is the world's third largest producer of rhenium.

Figure 37: Estimated revenues of KGHM Głogów Refinery, 2011 ($m)



Source: ILZSG (2012), Study of the By-Products of Copper, Nickel, Lead and Zinc

These revenue estimates should be considered to be at the upper end of what might be achievable, due to the fact that these refineries have already taken the decision to recover the by-product, and have sufficient data reported. Some gaps are evident in the data, although in general there is good coverage.

Conclusions

The research conducted in this section has investigated the relationships between the markets for by-products and the base metals from which they are usually derived. Data has been collected and reviewed for a number of dimensions relevant for the critical raw materials methodology including:

- The link to base metals, with data on the share of production from each source of by-product supply
- An estimate of by-product recovery as a percentage of that which is potentially available. This gives an indication how much additional supply is available in the short-to-medium term.
- An estimate of the revenues that are available for a specific by-product relative to the main product. This will reflect the incentives that exist for by-product recovery, both at existing refineries, and those for developing poly-metallic deposits on the basis of the economics of the by-product recovery.

The available data indicates a clear distinction between types of by-products:

- Major by-products, co-products: cobalt, gold, molybdenum, palladium, silver and possibly tantalum:
  - may have own primary production infrastructure
  - generally have high recovery efficiency, typically >60%
  - represent important sources of revenue, often considerably >10%.
- Minor by-products: gallium, germanium, hafnium, indium, rhenium, selenium and tellurium:
  - have very limited own production infrastructure
  - generally have lower recovery efficiencies, sometimes <40%
  - represent small contributions to revenues, typically <5%.

The resulting discussion highlighted instances where being a by-product metal may influence the supply of metals. For instance, it could be seen to reduce the supply risk due to quicker responses to prices or having a steady, stable source of supply. However, by-products are also exposed to some additional risks such as small market size, concentrated world production, price volatility (Section 5.5.1) and adding to the refining complexity. Some of these will already be captured within the existing methodology, such as country production concentration, but the others may not be. As highlighted by the cases studies a good material-by-material knowledge is required to understand the nuances of each, and information on by-production of metals is included within the profiles.

5.5 End-Use Stage

5.5.1 Price Volatility

Much of the criticality literature tends to focus on the likelihood of supply disruptions rather than their potential impact. Consequently the results are often easily overstated regarding the economic impact of a possible supply disruption to raw materials.

However, to understand and accurately quantify the potential economic impact of supply disruptions that might potentially happen is by no means a straightforward task. Historical evidence is available for the rises that can be witnessed during supply "crises" e.g. rare earths (2008-2011), vanadium (2005 & 2008) and tantalum (2000-2001) or during period of considerable supply constraint e.g. indium (2004-2007), molybdenum (2004-2008) and tin (2008 & 2011).

It is clearly not possible to estimate economic impact of supply disruption by material and by end-use industry within the scope of this study. However, this study does look to assess its quantification by examining price volatility as a proxy, which will be linked to the elasticity of supply and demand associated with each raw material and end-market. In future work this might be combined with the metric already developed for "economic importance" to reflect the number and identity of which sectors are affected by the supply disruption, and by how much. However, in this study it is used as a measure compare between materials.

The danger implicit, however, with any metric of price volatility is that is essentially backwards looking, and therefore makes the assumption that because a market has been volatile, it might continue to be more volatile in the future. This may not be the case, for example, should new major applications be discovered for particular raw materials.

Measures of price volatility

A number of historical price volatility indices are possible. Perhaps the simplest is to calculate the amplitude of the price movements by comparing the peak and the trough in prices over a certain period (Equation 1). This measure is useful in calculating the range and magnitude of price movements, clearly identifying the extent to which prices have increased (or decreased) within that period.

Equation 1: Historical price amplitude formula

$$Amplitude = \frac{P_{max}}{P_{min}}$$

A more holistic measure of historical price volatility is given by Equation 2. This formula is commonly applied for stock and commodity prices, such as by the Chicago Mercantile Exchange (CME), but has also been used by European Commission commodity price analyses.[a] The formula essentially calculates the standard deviation of period-to-period changes in prices, as computed by the natural logarithm of their ratio. In theory, the values calculated are unbounded, i.e. they can take any value up to infinity, although in practice it would take a rather extreme example to achieve a value greater than five.

Equation 2: Historical price volatility formula

$$Volatility = STDEV \cdot \left(\ln \frac{P_t}{P_{t-1}}\right) \cdot \sqrt{T}$$

$$STDEV = \sqrt{\frac{1}{T}\sum_{t}^{T}(P_t - \bar{P})^2}$$

Where $P_t$the price at period t, T is the total number of periods, STDEV is the standard deviation of prices, with $\overline{P}$ being the mean price
Source: CME Group, http://www.cmegroup.com/market-data/datamine-historical-data/methodology.html [accessed February 2013]

---

[a] See for example European Commission DG-AGRI (2009), Historical Price Volatility

This index will give the highest scores for sudden rather than gradual price changes, although no distinction is made between price rises and price falls. In practice, however, this is not much of a limitation, as raw materials producers will be most sensitive to price falls, whereas end-users will be most sensitive to price rises. In the extreme it could lead to mines or refiners closing down (with low prices), or manufacturers being squeezed with regard to their raw material input prices. Therefore both upward and downward price volatility could have significant adverse economic impacts on different types of European businesses.

Data availability

To provide the broadest coverage, there is a need to collate historical price data across all of the metal, mineral and biotic resources within the scope of the study.

For some raw materials, such as the base and precious metals, trading takes place on a daily basis through open public exchanges. The London Metal Exchange (LME) is the world's largest non-ferrous metals market, with annual trading volumes of $14.5 trillion for 2012.[a] It provides a transparent forum for all trading activity and it offers a range of futures and options to help to set the price of material months and years ahead (up to 27 months for base metals). This helps the physical industry to plan forward in a world subject to often severe and rapid price movements.

Other more speciality metals and alloys are traded through long-term supply contracts and individual trades between individual large consumers and suppliers as well as private trading houses.[b] Potential buyers and sellers can also list proposals on specialist websites that attempt to match counterparties together. The terms of such trades are generally unavailable publicly and a "market price" in the conventional sense does not exist. Publicly available price quotes, for example through sources such as *metal-pages.com*, actually represent expert estimates of representative prices in trades being executed on a particular day, which are compiled through recurring interviews with individual traders. These markets are therefore by their nature much smaller and more opaque than the exchange traded markets; and the range of financial products offered will be smaller and more costly (i.e. the transaction costs will generally be higher).

For the industrial minerals, the nature of trading of similar to that of these minor metals, i.e. through long-term supply contracts and individual trades. Pricing data is available from *Industrial Minerals* for all of the major minerals (of various grades and origins). Some metals, however, are very specialist and are neither traded on exchanges, nor are prices generally listed on websites such as *metal-pages.com* or *Industrial Minerals*. The markets for these metals are thus much less transparent, and limited information is available of quantities available or on prices. These metals include: beryllium and hafnium. To obtain a quote or trade in these metals, one would have to contact a specialist trader or look at aggregated annual data.

Where possible data of equivalent quality is preferable, which covers all of the metals, minerals and biotic raw materials. There is clearly more detailed information available for some of the raw materials, although it is not comprehensive across all of the raw materials within the scope of the study. Historical price data on a wide range of metals and minerals is readily available from the United States Geological Survey database.[c] This covers the abiotic raw materials within the scope of this study, i.e. for all of the metals and minerals. This data goes back to at least 1970 for all of the raw materials covered, and for some commodities it dates as far back as 1850. This data provides average annual or yearend historical price data, which, for ease of comparison and computation, has been deflated and indexed, with 1998 as the base year. Data for the biotic raw materials is available from the World Bank and IMF commodities price databases, which have also been averaged, deflated and indexed accordingly.

---

[a] See "About the LME", available at URL: http://www.lme.com/who.asp [accessed 23/07/2013]

[b] This discussion is drawn from European Commission JRC IET (2011), Critical metals in Strategic Energy Technologies

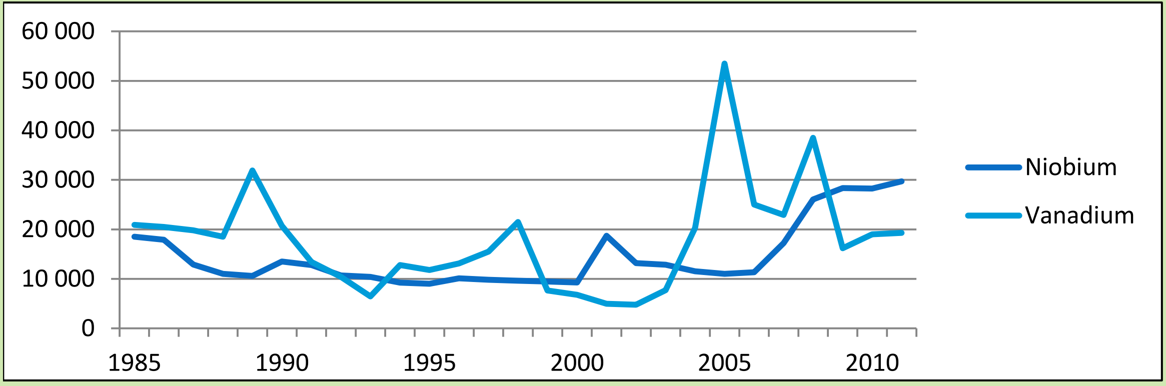
[c] USGS (2012-), Historical Statistics for Mineral and Material Commodities in the United States [accessed February 2013]

Case Study: How does price volatility affect end-users?

Niobium versus vanadium: Choices for steel alloying elements

Niobium and vanadium are both commonly used as alloying elements for high-strength low-alloy steel applications. Historically vanadium has been the larger market, although all this changed between 2004 and 2007, when the vanadium market suffered a prolonged period of high and volatile prices. In response, world niobium mine production increased significantly, as end-users partially substituted away from vanadium towards niobium, (whereas vanadium mine production plateaued). However, since 2008 this trend has started to reverse, now that niobium has become relatively more expensive.

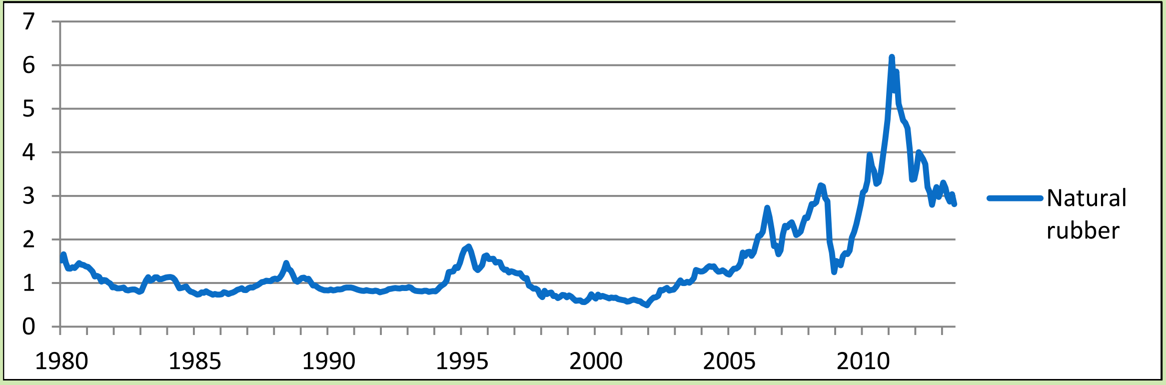
Figure: Niobium and Vanadium price history (98 US$/tonne)



Natural rubber: The need for greater market transparency

The major market for natural rubber is tyres, and EU industry is 100% import dependent on this raw material, largely from production concentrated in South East Asia. However, between February 2009 and February 2011 prices rose five-fold in response to rising world demand and a shortfall in supply due to a lack of rubber trees planted during 1997-2003 (which have a 7-10 gestation period before they can be harvested). The European Tyre and Rubber Manufacturers' Association (ETRMA) undertook a study to understand this price volatility and made a number of recommendations aimed at improving market transparency to ensure greater predictability and continuity in supply and prices.

Figure: Natural rubber price history, Singapore exchange ($/kg)



References: USGS/IMF historical price and production statistics and ETRMA (Dec 2011), presentation to the European Parliament

It is recognised that the use of this data represents a simplification of the picture of the economic impact for several reasons, such as the frequency of purchase/price negotiations by the end-user (which may more often than once a year), the existence of possibilities to hedge and have long-term contract (which may mitigate the impact of changes in spot prices) and the fact that averaging the data over the course of a year will smooth out some of the daily and monthly price fluctuations. However, this approach is necessary if there is a wish to have comprehensive data across such a large range and variety of raw materials. Nonetheless, it does illustrate the overall approach.

Results and interpretation

The results of this price volatility analysis are shown in Table 29 (using Equation 1 and Equation 2), which have been colour-coded and sorted to aid visualisation. These indices have been calculated for the last ten years, as this is probably most relevant time period for the current technologies and end-markets for the raw materials. However, it could be calculated for any period for which data exists (i.e. up to 40 years) or for separate periods (which would allow back-dating of the calculations to previous time periods and existing studies). Some differences would then be observable when comparing time periods.

Table 29: Historical price volatility index for key raw materials, over the past ten years. Critical raw materials in bold

Raw Material	Rank	Volatility	Amplitude
Vanadium	1	1.88	11.2
Selenium	2	1.81	12.4
REE (all)	3	1.69	13.4
Molybdenum	4	1.63	7.8
Rhenium	5	1.62	9.1
Tellurium	6	1.48	8.7
Indium	7	1.46	9.0
Cobalt	8	1.26	3.3
Manganese	9	1.20	4.2
Tungsten	10	1.14	4.4
PGMs	11	1.13	2.1
Zinc	12	1.09	3.7
Nickel	13	1.07	4.8
Germanium	14	1.03	3.4
Antimony	15	0.98	5.9
Tin	16	0.93	4.3
Chromium	17	0.92	3.9
Hafnium	18	0.90	2.5
Tantalum	19	0.85	3.7
Phosphate rock	20	0.85	3.9
Clays	21	0.84	2.0
Titanium	22	0.80	2.6
Magnesium	23	0.78	2.4
Copper	24	0.76	4.3
Potash	25	0.74	4.0
Silicon metal	26	0.74	2.4
Natural rubber	27	0.73	7.9
Beryllium	28	0.69	2.1
Niobium	29	0.69	2.7
Gallium	30	0.64	1.5
Lithium	31	0.63	2.8
Aluminium	32	0.59	1.7
Silver	33	0.56	6.1
Coking coal	34	0.54	5.1
Woodpulp	35	0.54	2.5
Bentonite	36	0.49	1.5
Gypsum	37	0.47	1.5
Bauxite	38	0.41	1.6
Natural graphite	39	0.41	2.0
Fluorspar	40	0.40	1.6
Diatomite	41	0.38	1.5
Borates	42	0.37	1.6
Talc	43	0.34	1.6
Magnesite	44	0.27	1.3
Feldspar	45	0.27	1.3
Barytes	46	0.23	1.8
Silica sand	47	0.23	2.2
Gold	48	0.22	4.0
Iron ore	49	0.21	3.2
Soft sawnwood	50	0.20	1.4
Limestone	51	0.11	1.4
Perlite	52	0.10	1.2

Key to colour scale:

Volatility:	0.0	0.25	0.5	0.75	1.0	1.25	1.5
Amplitude:	1.0	3.0	4.0	5.0	6.0	7.5	10.0

Over the last ten years vanadium, selenium, rare earths, molybdenum, rhenium, tellurium and indium have witnessed the greatest price volatility. These same metals have increased in price by around ten-fold at some point in the last ten years. It is noticeable that volatility is, in general, greater for speciality and by-product metals compared to bulk metals, with industrial minerals amongst the most stable commodities in terms of their prices. Woodpulp and soft sawnwood have quite low price volatility compared to the other raw materials analysed.

Comparison with the critical raw materials identified within this study demonstrates that there is no connection between criticality and price volatility, with critical raw materials appearing throughout the range of volatilities calculated. Indeed, the full range of volatilities is represented by the critical raw materials due to the inclusion by-products, speciality metals, bulk metals and industrial minerals in the list.

Some differences are apparent between the price volatility index and price amplitudes. In particular, natural rubber, silver, coking coal and gold have significantly peak-to-trough movements than that indicated by the year-to-year price volatility index. In contrast, platinum group metals and clays have a higher year-to-year price volatility compared to the amplitude of their price movements. These distinctions highlight additional richness in the results for price volatility. However, again there appears to be no link with the materials analysed as critical and their price amplitude.

The price volatility analysis has produced some useful and interesting results which are useful to examine within the context of this work, and that could be directly applied within the overall analysis in the future (this is explored in Annex H).

5.5.2 Environmental Legislation

Environmental legislation within the EU and Member States has the potential to regulate the manufacturing and placing on the market of certain substances that are demonstrated to be hazardous or pose a risk to human health and/or the environment. The purpose of this type of regulation is typically to provide greater understanding of the hazards associated with the substance through assessment and characterisation of the risk and level of human and environmental exposure to it. This allows safe management and usage of the substance, or in some cases limits or bans its use. These regulations may apply to specifically identified substances of interest or more broadly to all substances placed on the market.[a] Certain provisions within the legislation target specifically identified substances, for example Substances of Very High Concern (SVHC) in REACH or substances identified as carcinogenic, mutagenic or toxic for reproduction (CMR).

In general, legislation of this type applies to substances derived from raw materials as well as the raw materials themselves, though exceptions are made particularly at the EU level for certain raw materials. Whilst individual approaches may be taken in Member States, overarching regulation exists within the EU and at a global level. Of particular importance are:

- Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)
- Classification, Labelling and Packaging of substance and mixtures (CLP)

In addition to REACH, other regulations exist which ban or put in place limits on usage. For example the Restriction of Hazardous Substances Directive (RoHS) and the Stockholm Convention, place bans or restrictions on a small list of substances that are of particular concern globally, rather than evaluating a wide range of substances. At present these only impact a selective list of substances such as lead, hexavalent chromium or various specific hydrocarbon based substances for which particular concerns have been identified. However, additional substances may be added over time.

Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)
The EU REACH Regulation (EC Regulation No. 1907/2006) controls the production, import and use of chemical substances within the EU. It is designed to offer an integrated system for the registration, evaluation, authorisation and restriction of chemicals across all states and industries, and requires that businesses that manufacture and import chemicals identify, evaluate and manage the associated risks. Its core aims are to ensure a high level of protection to human health and the environment from the risks that can be posed by chemicals, the promotion of alternative test methods, the free circulation of substances on the internal market, and enhancing competitiveness and innovation. Other major countries and regions are known to be considering regulations similar to REACH, including, North America, China, and South Korea.[b]

All relevant substances must be registered with the European Chemicals Agency (ECHA), though for certain substances only notification of use is required. The information submitted through Registration

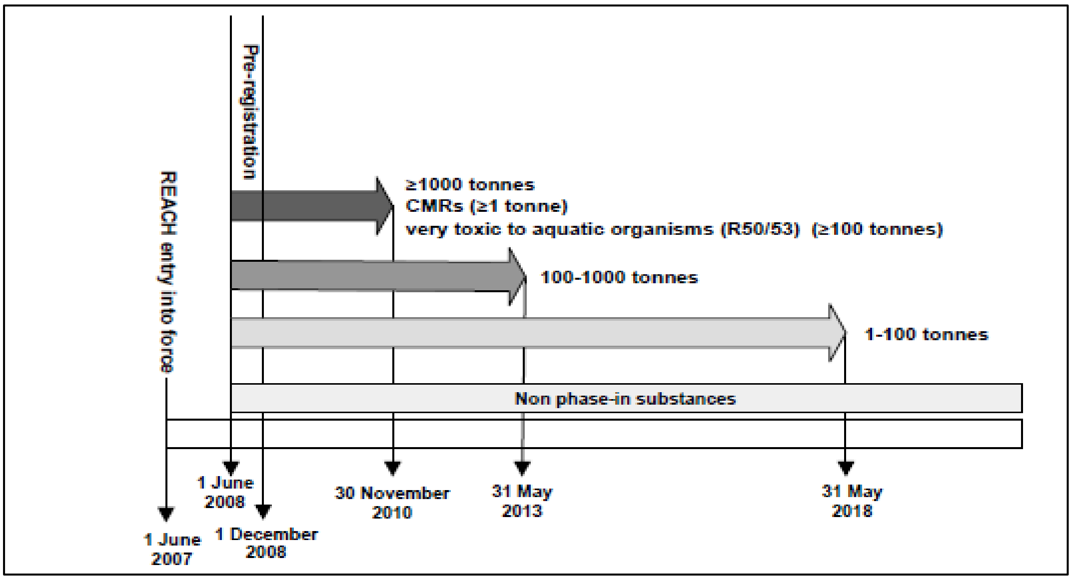
---

[a] Some substances are exempted under certain conditions, for instance certain medicinal products, radioactive substances and waste are exempt from REACH as they are already regulated by specific legislation.
[b] Metal Pages (January 2012), Cobalt sector urges rethink on EU REACH salts rules

identifies any hazards, with Evaluation, Authorisation and Restriction steps following on from this as necessary. The burden is placed on industry to demonstrate that the chemical substances placed on the market are safe both for human health and the environment. It is not just the chemical manufacturers that are subject to this legislation, but all downstream users of chemicals.

REACH came into force on the 1st June 2007, and it directly applies to member states. Registration is being applied in phases, based on the weight of substances manufactured and imported (Figure 38). The first phase included all substances with over 1,000 tonnes of production or import per year, as well as substances classified as CMR Category 1 and substances classified as very toxic for aquatic organisms. The first phase deadline for registration was 30 November 2010. The second deadline was on the 31 May 2013, with a limit of 100 tonnes per year. The final deadline is on 31 May 2018 for substances produced or imported in quantities over 1 tonne per year. ECHA provides a database of REACH registered substances and substances that have been identified for registration, along with relevant submitted dossiers.[a]

Figure 38: Timetable for the implementation of REACH



Source: European Commission

Certain substance categories are excluded from parts of the Regulation such as registration and assessment, though restrictions or other provisions may apply.[b] Exclusions include substances in foodstuffs, medicinal products, polymers (registration of component monomers is required), in process intermediates, and substances included in an article but not released. Of most relevance are naturally occurring substances that have not been chemically modified which are also exempted. This includes minerals, ores and ore concentrates; therefore some materials within the scope of this study fall into this category. [c]

In addition, a candidate list of Substances of Very High Concern (SVHCs) is maintained for potential inclusion in Annex XIV of the REACH Regulation which lists the substances subject to authorisation obligations. This list applies to substances for which current restrictions (e.g. for CMR) are viewed as insufficient, and a Risk Management Option is then used to identify the most appropriate legislative measure to apply. Whilst a substance being listed on the candidate list does not represent an outright ban, inclusion indicates that a substance may require authorisation for a specific use in the future. This can clearly be viewed negatively and may influence businesses and markets. At present this list includes 144 different substances or classes of substances.

---

[a] http://echa.europa.eu/

[b] A full list is provided in REACH Annex V

[c] For instance the aluminium ore bauxite requires Notification but not Registration, however aluminium requires Registration

Influence on criticality of raw materials

The nature and purpose of REACH means that it may influence the availability and use of some substances, including some raw materials as defined within this study. Registration and evaluation does not implicitly limit the availability of a substance, rather the consequences of the Evaluation stage may result in certain restrictions or requirements. However, the requirement to register a substance may, due to the resources required to register a substance, limit the availability of certain substances. Manufacturers have identified several risks to business resulting from REACH, for example[a]:

- disrupted supply due to unavailability of substances
- consequent impact on products containing substances
- possible reputational damage due to compliance issues
- loss of business
- threat of fines and prosecution.

From a raw materials producers' perspective, there is clearly the possibility of diminishing demand from the EU market or causing a shift in processing of the raw materials outside the EU if restrictions become too severe or due to the impact of listing on the SVHC candidate list.

In terms of raw material supply the direct impact appears limited. Certain restrictions may be placed on the raw materials (though many are exempt) if registration is required. The differences in materials considered across this study means that there is no consistent baseline across all. Some materials are refined products that may require intermediate processing or reliance on other substances that require registration themselves. Some, such as the industrial minerals and ores, may be a product in themselves. Others sit between, leading to variance in requirements. In addition, the definition of "not chemically modified" and other terms may be interpreted differently across materials or production chains, leading to uncertainty over how the regulation is applied.

However, REACH includes almost all substances coming on to the market, including chemically modified substances derived from raw materials. These modified substances are generally those incorporated into end-use applications identified within this study. Therefore registration or lack of registration may affect the availability of a substance for a use, and consequently the industry relying on this substance. This is more likely to be evident in smaller markets as the lower weight boundaries come into force and the financial motivation to register may be less. In other circumstances REACH registration may be seen to reduce supply and use issues with a substance, by providing detailed information on associated hazards and risk; however, there are barriers associated with the original registration.

Therefore REACH may influence the downstream application demand for some materials, requiring an understanding of the full value chain for these substances and applications to fully understand this. The phased approach to registration also makes this more complex; whilst production and import figures for the raw materials are known in many cases, this does not necessarily reflect the REACH status of all materials along the full supply chain. There may also be substances essential for processing or manufacturing which also require consideration, which are not present in an end product.

As a result, on one hand the demand for a material may be reduced, but this could lead to a more concentrated supply outside the EU, and a different composition of applications for the materials. On the other, demand could increase with certainty over availability of a specific material. Therefore gauging the overall impact on a raw material criticality would require an understanding of the complete supply chain for each application of a raw material, which is outside the scope of this study. From this perspective it may be more appropriate to consider this influence when criticality of materials associated with a specific application is considered.

The SVHC candidate list can be used to identify which raw materials considered in this study have related substances that might be subject to authorisation requirements. Restricted substances are listed in

---

[a] http://www.eef.org.uk/reach/default.htm, accessed 22/09/2013

Annex XIV and Annex XVII of the Regulation. Of a total of one hundred and forty four substances on the list, thirty eight are linked to the abiotic raw materials included in this study (Table 30). Most are included due to being classified carcinogenic and/or toxic to reproduction.

Table 30: SVHC linked to raw materials in scope (critical raw materials are underlined)

Materials	Count	Substances on the SVHC Candidate List
Aluminium/ Bauxite	2	Zirconia aluminosilicate refractory ceramic fibres, Aluminosilicate refractory ceramic fibres
Antimony	1	Pyrochlore (antimony lead yellow)
Barytes	1	Silicic acid barium salt (lead-doped)
Borates	5	Diboron trioxide, Tetraboron disodium heptaoxide(hydrate), Boric acid, Disodium tetraborate, Lead bis(tetrafluoroborate)
Chromium	12	Dichromium tris(chromate), Pentazinc chromate octahydroxide, Potassium hydroxyoctaoxodizincatedichromate, Chromic acid and Dichromic acid (and oligomers), Chromium trioxide, Ammonium dichromate, Sodium chromate, Potassium chromate, Lead sulfochromate yellow (C.I. Pigment Yellow 34), Lead chromate, Sodium dichromate, Lead chromate molybdate sulphate red (C.I. Pigment Red 104)
Cobalt	5	Cobalt dichloride, Cobalt(II) diacetate, Cobalt(II) sulphate, Cobalt(II) carbonate, Cobalt(II) dinitrate
Fluorspar	7	Ammonium pentadecafluorooctanoate (APFO), Pentadecafluorooctanoic acid (PFOA), Henicosafluoroundecanoic acid, Lead bis(tetrafluoroborate), Heptacosafluoro-tetradecanoic acid, Tricosafluorododecanoic acid, Pentacosafluorotridecanoic acid
Molybdenum	1	Lead chromate molybdate sulphate red (C.I. Pigment Red 104)
Phosphate Rock	2	Trilead dioxide phosphonate, Tris(2-chloroethyl)phosphate
Silicon	2	Zirconia Aluminosilicate Refractory Ceramic Fibres, Aluminosilicate Refractory Ceramic Fibres
Tin	2	Dibutyltin dichloride (DBTC), Bis(tributyltin)oxide (TBTO)
Titanium	2	Lead titanium zirconium oxide, Lead titanium trioxide

Of the materials in scope for this study, chromium and fluorine based substances have the highest number of entries on the SVHC candidate list; these are both critical raw materials. Of other materials, lead is the most strongly influenced in terms of number of substances, with twenty nine included in the candidate list. However, as with the registrations, this indirectly influences the criticality of raw materials as it is more closely linked to downstream applications rather than access to the raw materials.

Classification, labelling and packaging of substance and mixtures (CLP)
Within the EU, European Regulation (EC) No 1272/2008 on classification, labelling and packaging of substances and mixtures has been implemented to adopt the United Nations' Globally Harmonised System on the classification and labelling of chemicals (GHS). This came into force in the EU on 20th January 2009. To allow phasing from existing systems used in Member States, the new rules have been directly applied to all EU Member States since December 2010 for substances and from June 2015 for mixtures.[a] This legislation draws upon the registration of substances under the REACH regulation; though the same obligations for assessment of potential hazardous properties and for notification of classification of hazardous substances are still required where no REACH dossier exists.

The aim of this legislation is to ensure that the hazards presented by chemicals are clearly communicated to workers and consumers, and harmonise the approach across the EU. Prior to placing substances and mixtures on the market, risks to human and the environmental must be classified in line with identified hazards. Hazards must then be labelled according to a standardised system using statements, labels and safety data sheets. Therefore suppliers are required to undertake classification exercises to enable correct labelling and packaging. Suppliers of substances classified as hazardous are required to notify the

---

[a] http://echa.europa.eu/regulations

ECHA within a month of the substance being placed on the market; for importers it is one month from physical introduction to the customs territory of the EU.

Influence on criticality of raw materials
The overall impact of CLP on materials supply is yet to be seen due to the phasing in over several years. In many cases this will take over from Member States' existing legislation to harmonise the approach across the EU. Some manufacturers have identified potential risks associated with this process. For instance the harmonisation process across Member States may result in the reclassification of substances; this could have consequences for complying with other legislation (such as for transport or waste) or influence downstream markets.

In terms of supply and access to raw materials this is an indirect consideration, similarly to REACH, which is influencing upstream uses and applications, rather than the supply itself. Therefore it is not considered further within this study.

Conclusions
The complexity of this type of legislation, its on-going implementation and links across supply chains make it difficult to fully understand any impact on the criticality of raw materials. Whilst these regulations may influence access to and handling of certain substances, they do not reflect an intrinsic property of the supply of the raw materials unless outright bans or restrictions on raw materials are in place.

However, there is a more direct link between this legislation and criticality through influencing the demand for substances derived from the raw materials themselves, or demand from applications. From an EU perspective there is scope for influencing EU supply of raw materials and related products. Market restrictions caused by implementation of legislation, or overall "regulatory burden" could be viewed as impacting on both supply of raw materials through influencing the demand for substances derived from raw materials. To fully understand this, an assessment of upstream uses of raw materials may be necessary to gain a full picture; therefore this is more relevant to application based criticality studies, or examinations of supply chain risk.

5.6 Summary and Conclusions for Additional Influences

Within this section, eight further potential influences on the criticality of raw materials have been discussed (Table 31). These chapters considered the potential impact on criticality and, in some instances, inclusion in a revised methodology. Overall it was found that many of these influences were relevant, but they were perhaps not as directly influential on the criticality of raw materials as the core factors currently assessed. Perhaps the most directly relevant analysis was comparing minerals and metal production, where it was shown that this can strongly influence the supply risk of a metal or ore. This should be taken into consideration when discussing these results and in future studies, and may form the basis of wider analysis of supply risks.

In addition, two factors were identified that could add richness to the quantitative methodology; corporate concentration and price volatility. By contrast, the direct inclusion of other factors (ore grade indicators, land use, mining governance, by-production dynamics and environmental legislation) are not deemed practicable or believed to add substantial depth to the work.

Examination of each factor is useful for providing further insight into raw material supply and demand, and helping inform which measures taken for reducing risk are most suitable. For instance the land use analysis and mining governance provide useful information over where might be most suitable to source or begin mining (critical) raw materials. The by-production analysis demonstrates that the influence of other linked materials markets need to be taken into careful consideration when considering developing by-production. The impact of environmental legislation needs to be considered along the supply chain, with the impacts on applications, manufacturing location and raw material demand examined.

Table 31: Summary of influences on criticality

Influence	Summary	Conclusion
Ore grades	Ore grades were examined in relation to criticality and found to be not directly relevant in short to medium term considerations, and potentially misleading if misinterpreted.	Whilst this is an important and complex topic, it is not directly relevant to the EU approach to assessing criticality. Other studies have included it where a longer timescale is considered.
Land use	Competing land uses within the EU, such as those protected by Natura2000, were identified as a possible influence on developing indigenous raw material supply. Natura2000 sites were compared to known deposits and mines to identify where competition for land may exist	Overall it was found there was some overlap between Natura2000 sites and known deposits. However, existing mining activities indicated this was unlikely to be a limiting factor in deposit development.
Mining governance	Three schemes were discussed; however, each had limited coverage of the materials and/or countries under investigation, suggesting little influence over supply risk. However, the data aligned well with the WGI supporting its use as a proxy in this assessment	Analysis supports the continuing use of the WGI in the assessment. Some raw materials supply options from “low-risk” countries exist, and in the longer term development of these schemes may help to reduce supply risk concerns.
Corporate concentration	Corporate concentration was examined in parallel to country concentration. From a limited assessment, some parallels were found, particularly for niobium, and the assessment works for supply based on company as well on a country basis.	Wider data would allow analysis over more materials. This could form part of a quantitative methodology, discussed in Annex H
Metal and refining production	Concerns were raised that different stages of processing may lead to substantially different supply risks. Supply risk analysis of several ores and metals was conducted to assess this impact.	It was found that the stage of processing can influence the supply risk of a metal or ore. In some cases the impact was large, in others negligible. This is one area which could be explored further.
By-production dynamics	Many of the metals assessed within this study are by-products of other primary production. It was discussed if this presented an additional supply risk through examining these supply of these metals.	By-production is a complex issue, and not easily quantified. Each by-product requires an individual consideration, and a universal approach cannot be made.
Price volatility	The historic price volatility of the materials was calculated, and how this impacted on the criticality of raw materials was examined. No correlation between the critical raw materials and price volatility was identified; however, this could be another factor to consider due to the impacts of price fluctuations.	Data availability and existing quantification methods suggest that this could be included in a revised methodology, see Annex H
Environmental legislation	Environmental legislation was identified as potentially having an impact criticality through raw material supply and their markets. REACH was of particular concern. However this is more likely to influence downstream markets for materials; the impact on criticality is uncertain.	Whilst this is an important issue for producers and users of raw materials, the greatest impact is along the supply chain. Identifying the knock-on effect on criticality requires a wider understanding of supply chains.

6 Criticality Analysis of Biotic Materials

6.1 Introduction

Biotic raw materials are materials which are derived from renewable biological resources that are of organic origin but not of fossil origin. Biotic materials have been included within this criticality study as a result of concerns over limited supply and issues relating to responsible and sustainable sourcing, as seen for other raw materials. Biotic materials are used extensively throughout Europe and the world as raw materials, for instance wood is used in similar tonnages to steel. However, their use is small compared to that of food and feed; in 2008 around 4% of harvested agricultural biomass grown worldwide was used for industrial materials usage with over 90% being used for food and feed.[a] Examples of biotic raw materials and groups of biotic materials are shown in Table 32.

Table 32: Examples of biotic materials

Wood	Chemical pulp	Palm oil	Cotton	Straw
Natural rubber	Natural fibres	Vegetable oils	Hemp	Animal fats
Cork	Sugar	Starch	Medicinal plants	Lignin

In contrast to abiotic materials such as minerals and metals, biotic materials are obtained from renewable resources and not static reserves. They can be obtained from renewable resources from forestry and agriculture which are specifically produced for materials usage. However, they can also be obtained from biogenic residues, such as wastes from agriculture, organic wastes and animal fats.[b] Many biotic materials are used as precursors for producing bio-based adhesives, chemicals and polymers that can be used as alternatives to traditional petroleum based products. Bio-based resources can be used in a wide range of applications; it is convenient to categorise their applications by what they supply[c]:

- Materials: used with slight modification, for example wood for timber
- Substances: using crops to produce a substance and then isolating it, for example starch for glues and additives or bio-oil for transport fuel
- Building blocks: breaking down biomass to form building blocks for chemical synthesis, for example ethanol for bio-plastics.

In order to assess biotic materials in the same criticality framework as abiotic raw materials, it was first necessary to determine the suitability of this framework for biotic materials. Once exemplar biotic materials were chosen, their data availability and conformity to the criticality indicators were reviewed. Following this review, a criticality assessment of the chosen biotic raw materials was undertaken and the results and other issues surrounding the assessment are to be discussed in due course.

6.2 Scope and Discussion on Materials

In order for the scope to be analogous to that for abiotic materials, only non-energy, non-food biotic materials are under consideration. In the first instance natural rubber, sawn soft wood and pulp wood have been chosen as exemplar biotic materials.

Whilst the selection of natural rubber was simple, the selection of a wood type was more complex. Initially the inclusion of industrial coniferous roundwood was considered, using the CN code classification (Figure 39).

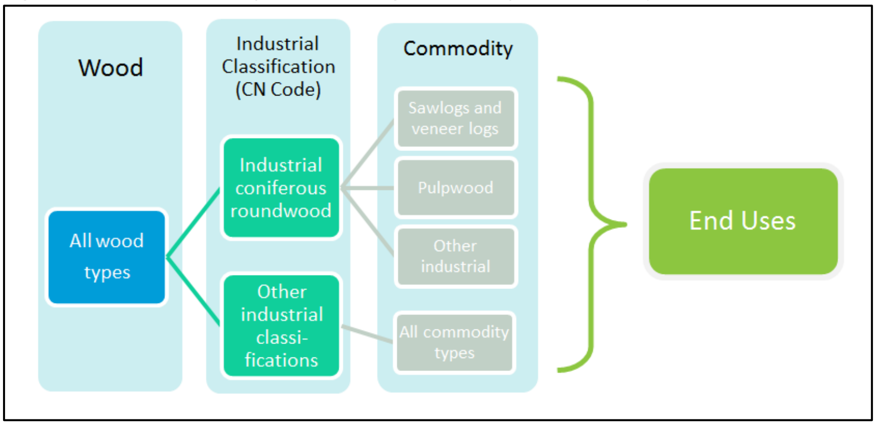
---

[a] Nova-Institute (2013), Food or non-food: Which agricultural feedstocks are best for industrial uses?

[b] Nova-Institute (2012), Industrial material use of biomass: Basic data for Germany, Europe and the World.

[c] Institute for Fuels and Renewable Energy (PL) (2008), Review of the current situation for land use in the EU27, Future Crops for Food, Feed, Fibre and Fuel, FP7 project (WP1).

Figure 39: Schematic of wood categorisation for this study



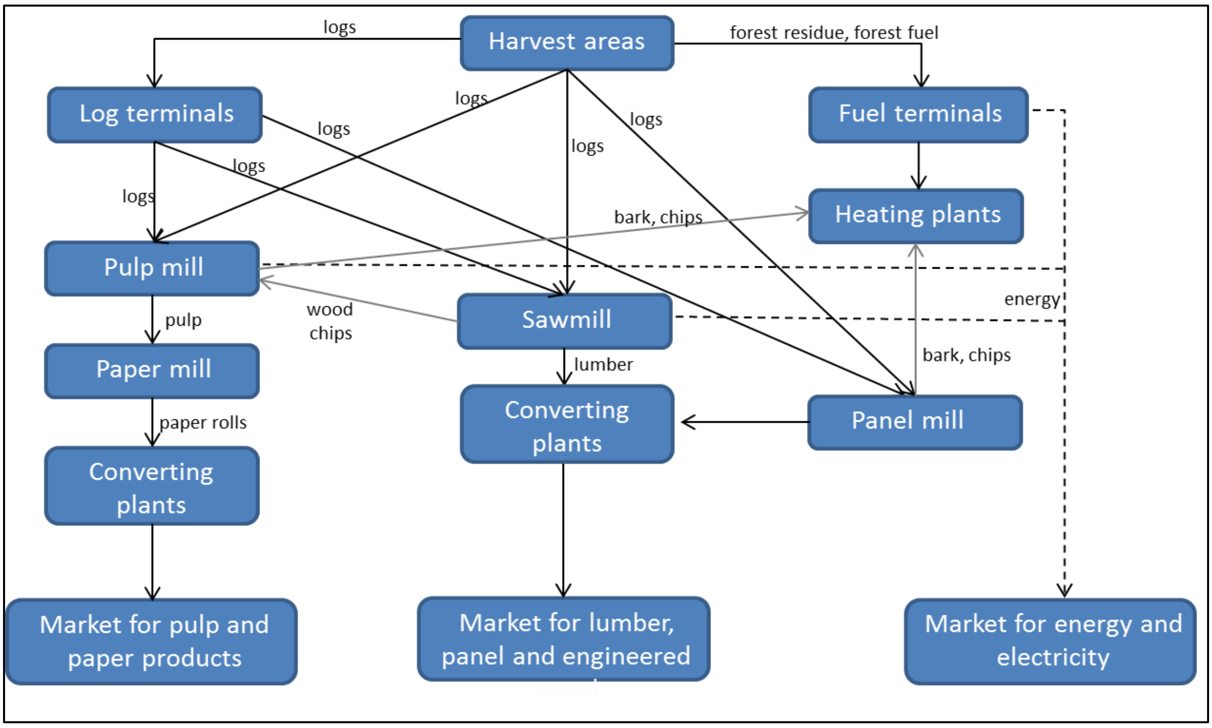
This categorisation also omits wood used for biofuels, which is outside the remit of this work.

At this categorisation level industrial roundwood can be considered as an aggregation of three commodities:

- Sawlogs and veneer logs.
- Pulpwood, round and split.
- Other industrial.

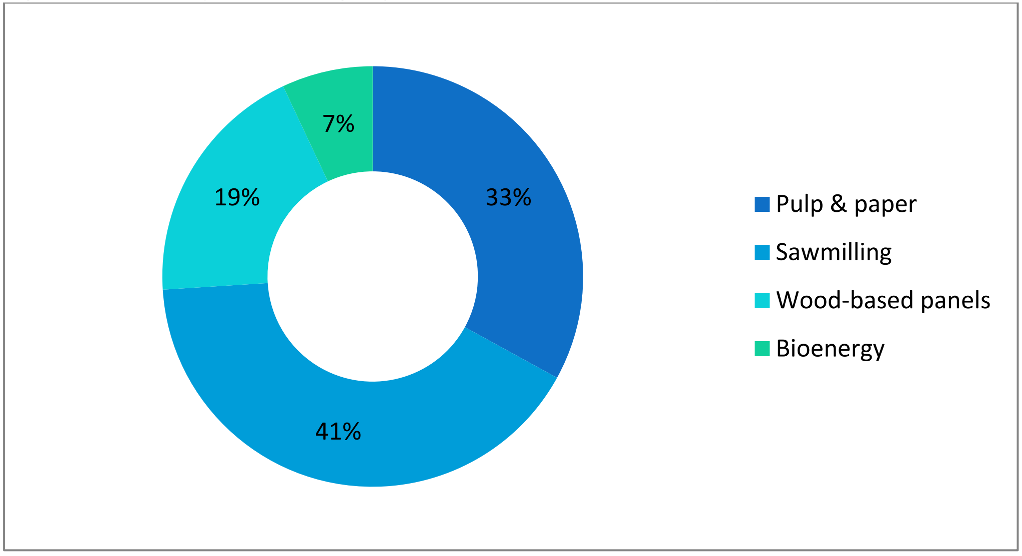
However, this categorisation does not relate directly to the end-sector uses for industrial roundwood and as such the necessary data will not be readily available. These wood commodities are used by forestry industries to produce a range of primary wood products, which are then used as raw materials by other sectors. Forest products have a complicated supply chain, with a significant amount of overlap between different end-sectors. For instance wood chips from the sawmill industry often feed directly into the supply chain for pulp mills. A summary of the different supply chains is shown in Figure 40.

Figure 40: Schematic of supply chains for forest products



Following stakeholder engagement it was determined that the two most important industrial end-users of industrial roundwood to the EU economy are the sawmilling and pulp and paper industry. This is demonstrated in Figure 41, which shows the annual use of industrial roundwood by industry sector in cubic metres. The primary wood products used by these industries are sawn softwood and pulpwood. However, as an initial data scooping exercise revealed that end-sector usage data is not available by wood species, it was decided to study both coniferous and non-coniferous pulpwood as an aggregated raw material. Additionally, recycling data for paper and card is not reported by the wood species.

Figure 41: Industry sector usage of industrial roundwood in m^3 per annum



Source: Pöyry, FAO STAT.

In summary, pulpwood for use in paper and sawn softwood were chosen for further investigation. Pulpwood has been chosen for its importance as a raw material to the European paper industries; pulpwood is either logs or woodchips which are used for production of pulp for the paper industries. It is used along with pulp from recycled paper and non-fibrous material to produce paper and board. In 2012 CEPI countries consumed 1,429,000m^3 of wood in the production of paper of board of which less than 20% was imported.[a]

Sawn softwood has been chosen for its importance to both the construction and furniture industries in Europe. Sawnwood is a processed wood product which is produced by the forest processing industry and used as a raw material by other industries outside of the forestry sector. End uses of sawn softwood include construction, joinery, furniture and packaging such as pallets. In addition, these wood products have been chosen as the end-sector usage data was determined to be more readily available for them than for industrial roundwood as a whole.

These biotic raw materials have been chosen as a starting point as examples to evaluate the criticality assessment of biotic materials. However, this should not preclude the criticality assessment of other biotic materials. In keeping with the current assessment other primary wood products should also be considered for future studies; this could include wood-based panels, sawn hardwood and sawn tropical wood. Additionally, it may be of merit to consider coniferous industrial roundwood at the commodity level, if suitable end-sector usage data can be acquired.

As for other biotic raw materials, if the necessary data is available it should be possible to study any biotic raw material of forestry or agricultural origin. It is suggested that oil and fibre crops such as rapeseed, flax and hemp should as be considered, as these crops can be cultivated in Europe. The data availability should be assessed on a case-by-case basis before attempting a criticality assessment on a biotic material.

---

[a] Confederation of European Paper Industries (CEPI)(2013), Key Statistics – European pulp and paper industry 2012. CEPI member countries in 2012: Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Norway, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, The Netherlands, United Kingdom.

Examples of other biotic materials which could be studied include:

- palm oil
- cotton
- cork
- medicinal plants.

6.3 *Review of Criticality Methodology for Biotic Materials*

6.3.1 Criticality of biotic materials

No comparable criticality studies which assess biotic materials in a similar fashion to abiotic raw materials have been identified. In this instance a raw material is termed critical when the risks of supply shortage and their impact on the economy are higher when compared to other raw materials.

Although considerably less studied than bioenergy, several studies which investigate the materials usage of biomass have been identified. The motivation and focus of these studies is somewhat different to that of the present study, for example focusing on a specific application or issue. Additionally, no comparisons are made between different materials and as such there are no rankings. However, there are some aspects of these studies which are of relevance to criticality such as the end-sector usages which biotic materials account for and the threats to supply which they experience.

These studies include:

- Use of renewable raw materials with special emphasis on chemical industry, EEA, 2010.[a]
- Bio-based Economy in the EU-27: A first quantitative assessment of biomass use in the EU industry, nova-Institute, 2012.[b]
- Industrial material use of biomass: Basic data for Germany, Europe and the World, nova-Institute, 2012.[c]
- A review of national resource strategies and Research, Defra, 2012.[d]
- Raw Materials Critical to the Scottish Economy, SNIFFER, 2011
- Assessing the environmental impacts of consumption and production: priority products and materials, UNEP International Panel for Sustainable Resource Management, 2010.[e]
- Critical materials in the Dutch economy, Statistics Netherlands, 2010.[f]
- EPOBIO (FP6 project) – realising the economic potential of plant-derived raw materials
- U.S. Billion-Ton update: Biomass supply for a bioenergy and bioproducts industry, U.S. Department of Energy, 2011.[g]
- Crops 2 Industry: Non-food crops to industry schemes in EU27 (FP7 funded project) 2012.[h]
- 4F Crops: Future Crops for Food, Feed, Fibre and Fuel (FP7 funded project) 2008-2010.[i]

Studies identified which focus on natural rubber or wood:

- EU-PEARLS (FP7 project) Assesses EU-based production and exploration of alternative rubber and latex sources[j]
- Understanding Natural Rubber Price Volatility, a study for the ETRMA, Steptoe & Johnson, December 2011[a].

---

[a] European Environment Agency (2010), Use of renewable raw materials with special emphasis on chemical industry. Authored by European Topic Centre on Sustainable Consumption and Production and Nova-Institute,

[b] Nova-Institute (2012), Bio-based economy in the EU-27: A first quantitative assessment of the biomass use in the EU industry.

[c] Nova-Institute (2012), Industrial material use of biomass: Basic data for Germany, Europe and the World.

[d] Defra (UK) (2012), A review of national resource strategies and research.

[e] United Nations Environment Programme (2010), Assessing the environmental impacts of consumption and production: priority products and materials.

[f] Statistics Netherlands (2010), Critical materials in the Dutch Economy,

[g] U.S. Department of Energy (2011), U.S. Billion-ton update – biomass supply for a bioenergy and bioproducts industry.

[h] http://www.crops2industry.eu/index.html accessed September 2013

[i] http://www.4fcrops.eu/ accessed September 2013

[j] http://www.wageningenur.nl/en/Research-Results/Projects-and-programmes/eu-pearls-projects.htm accessed June 2013

- Wood flows in Europe, a study commissioned by CEPI and CEI-Bois (Mantau, 2012)[b]
- The importance of wood products and the wood products industry in EU policy making (CEI-Bois, 2012)[c]
- Good practice guidance of sustainable mobilisation of wood in Europe (DG AGRI/UNECE/FAO, 2010)[d]
- Study on the wood raw material supply and demand for the EU wood-processing industries, (DG ENTR, on-going).

6.3.2 Assessment of existing methodology

Before conducting the criticality assessment of biotic materials it was necessary to determine the suitability of the existing methodology. Both the appropriateness of each measure and access to the necessary data has been examined. This was deemed necessary as the methodology was developed for abiotic materials such as metals and minerals.

Overall the data availability for biotic materials was found to be poor in comparison to many of abiotic materials, in particular for end use sectors and recycling. However, it is comparable to some less reported materials. Assessing the majority of biotic raw materials using the existing high level methodology was found to be technically feasible.

For natural rubber the data required for the assessment is available or can be easily approximated. As a raw material, wood is complex and many of the specific issues which its supply faces are not necessarily addressed by the existing methodology.

The existing methodology uses three high level indicators to assess the criticality of materials; a detailed discussion of the data availability and suitability of these indicators follows. A more complete description of the methodology is provided in Annex B.

Economic importance indicator
As the value of a raw material to the economy far surpasses the value of the raw material itself, the economic importance of non-energy raw materials may be better assessed by the value of the products that depend on these. The reasoning behind the methodological approach for assessing economic importance of raw materials holds true for both abiotic and biotic materials. Both are approached at a similar level of detail.

In methodological terms, studying this aspect should be relatively straightforward for biotic materials. For each material the relative economic importance is calculated using the net consumption of the raw material and the value of the corresponding megasector.

The economic importance indicator is assessed by the aggregation of two factors: the share of consumption by an end-use megasector and the relative economic importance of that sector. The feasibility of studying these indicators with respect to biotic materials, in particular natural rubber, soft sawnwood and pulpwood, is discussed below.

Share of consumption by end-use sector
For this factor the end-uses and corresponding percentage of net demand for the biotic material under investigation are required. The necessary data required to determine the share of consumption of a material by a given end-use sector should be collected from information sources which are available to the members of the group. However, for biotic materials the data sources are different to those used for

---

[a] Steptoe & Johnson (2011), Understanding natural rubber price volatility – a study for the ETRMA.
[b] U. Mantau, commissioned by CEPI Confederation of European Paper Industries and CEI-Bois European Confederation of Woodworking Industries (2012), Wood Flows in Europe.
[c] CEI-Bois (2012), The importance of wood products and the wood products industry in EU policy making.
[d] DG Agriculture and Rural Development, Forest Europe, and United Nations Timber section (2010), Good practice guidance on the sustainable mobilisation of wood in Europe.

abiotic materials. Where possible, external stakeholders and members of the AHWG have been used to verify the data sources. Data has been gathered for the example materials; this is shown in the material's profiles.

For natural rubber the most significant end-user is the tyre industry, accounting for around 75% of annual consumption. Unfortunately, detailed data is not readily available on the end-sector uses of natural rubber other than tyres. For soft sawnwood, the following megasectors are of economic importance: construction materials, wood and other final consumer goods. For pulpwood, the only megasector of economic importance for this study is paper.

Economic importance of each sector which requires the raw material

This factor is not reliant on data which is specific to the material in question; as such there will be no difference when considering abiotic or biotic materials. The economic importance of each megasector is estimated by summing the gross value added of each NACE code contained within each megasector. Therefore the only requirement for this factor is that the end-use sectors of the material under study can be assigned to the megasectors.

Supply Risks

The supply of renewable biotic materials, such as wood and natural rubber, is fundamentally different to that of abiotic materials. For example, biotic resources regenerate over time with a limited stock at any one time. In the examples used there is significant wood production within the EU and no natural rubber production. In contrast most abiotic materials are supplied from static but large resources, mostly outside the EU.

The risk arising from supply is assumed to be concentrated from countries exhibiting poor governance (because the supply may be interrupted) or low environmental standards. As such, the present methodology treats these two elements of supply risk separately. In addition, recycling and substitution of the raw material can mitigate supply risks and are included in this indicator.
The existing methodology uses a combination of four factors to assess the risks associated with supply, namely:

- the extent to which the material can be substituted
- contribution of recycling
- concentration of producing countries
- poor governance/environmental performance of producing countries.

These factors require several data sets, which are common for minerals and metals but may not be directly available for biotic materials. Examples of data sets include recycling levels and country level production statistics.

Extent to which the material can be substituted

Both abiotic and biotic raw materials are used in products to provide a function. It should be possible to substitute one raw material for another, provided the intended function is adequately performed by the substitute. For biotic materials, this may involve using a different biotic material, synthetic version of the biotic material or an abiotic material. For example in some cases it is possible to substitute natural rubber for synthetic rubber.

The current methodology accounts for substitutability in a quantitative manor by end-use sector. For this assessment both end-sector use and the corresponding substitutability index are required. The index was estimated by expert judgement and subject to review by experts internal and external to the AHWG. It is possible to apply the same procedure for assessing the substitutability of biotic materials.

The availability of end-sector usage data for biotic materials, in particular soft sawnwood and natural rubber, has been discussed in relation to the economic importance indicator. Due to the varying amounts of natural rubber, substitutability should be assessed by tyre type (e.g. car, truck or 4x4). This can then be aggregated into a single substitutability score for tyres.

Contribution of recycling
The supply of raw materials is not met solely by primary production but also from secondary sources. Risks from primary supply are reduced by secondary production, as risks assigned to the producing countries do not apply to material recycled within the EU. The assessment only considers recycling from old scrap and not new scrap in the calculation of supply risk. The extent to which raw material consumption can be met from recycling of materials in the EU is taken into consideration.

For biotic materials closed-loop recycling is rarely technically feasible and where recycling occurs the product materials are often used in lower-grade products. For some wood products, quantifying the recycling rate will be complex; the available data for recycling of wood products does not correspond easily to the production figures.

For natural rubber, comprehensive data exists for tyre recycling and re-use for the majority of EU member states. In 2010 materials recycling accounted for 40% of end-of-life tyre arisings and retreading a further 8%[a]. Closed-loop recycling of tyres is not technically feasible, as no commercial process exists which can separate the different rubber components. Instead natural rubber is recovered as a mixture from tyres and is used in other rubber products. Rubber from tyres can be recycled in the form of rubber granulate and powder; this can then be used as moulded rubber in products such as wheels for caddies and dustbins and urban furniture. There is no data for other uses of rubber; it is thought that natural rubber used in these applications is not collected for recovery or recycling.

For wood recycling data is commonly assessed by end-product, for example recycling data and rates exist for paper recycling in Europe. However, this data will not include information such as wood species or which industrial wood product it has been derived from. For other wood end-products such as furniture and construction materials recycling rates are less comprehensive. This is partly due the high levels of market segregation and complexity of the products. It is theoretically possible to recycle some industrial wood products such as MDF in a closed-loop fashion.

Concentration of producing countries
The concentration of production at country level is assessed by modifying the Herfindahl-Hirshmann Index in two ways: by performing the calculations using production at a country level instead of at a company level and by multiplying the share of production of each country by its score in the World Governance Index, published regularly by the World Bank.[b]

The data requirements for this indicator are the country of production and its percentage share of world production of the raw material. For the raw materials in focus, natural rubber and coniferous industrial roundwood, the necessary data is available. Therefore it has been possible to assess the concentration of producing countries of biotic materials using the existing methodology.

Extensive production data is available from FAO STAT and Eurostat for a wide range of biotic materials, including natural rubber and all industrial wood products. For each country an indication of the data quality is provided. In conclusion, there is sufficient data available for assessing the concentration of producing countries for biotic materials. For further analysis, import and export value data is also available from the UNECE/FAO database.

In contrast to the majority of the abiotic materials considered in this study, a significant proportion of the wood consumed in the EU is produced in the EU, or within the European Economic Area. Therefore, when considering the supply risks perhaps only European countries should be under consideration for

---

[a] ETRMA (2011), End of life tyres, a valuable resource with growing potential.
[b] http://info.worldbank.org/governance/wgi/sc_country.asp, accessed September 2013

wood. By taking into consideration a global production of wood, the supply risk may be characterised by countries with low governance and environmental standards, which do not in fact supply wood to Europe. This may be further assessed by wood categories to determine whether for any of these the supply cannot be met by European sources.

Poor governance of producing countries

The stability or instability of the producing countries is estimated by using the WGI provided by the World Bank. For this process the only data requirement is the producing countries of the material. Consequently, there is no significant difference for assessing this factor for biotic or abiotic materials.

Environmental country risk

This indicator uses similar measures to poor governance of producing countries supply indicator, with the EPI used in place of the WGI. This indicator acts as gauge for establishing how close a country is to established environmental policy goals. For biotic materials there is sufficient data to assess this indicator using the existing methodology. However, wider input may be needed to provide a comprehensive view of environmental supply risk.

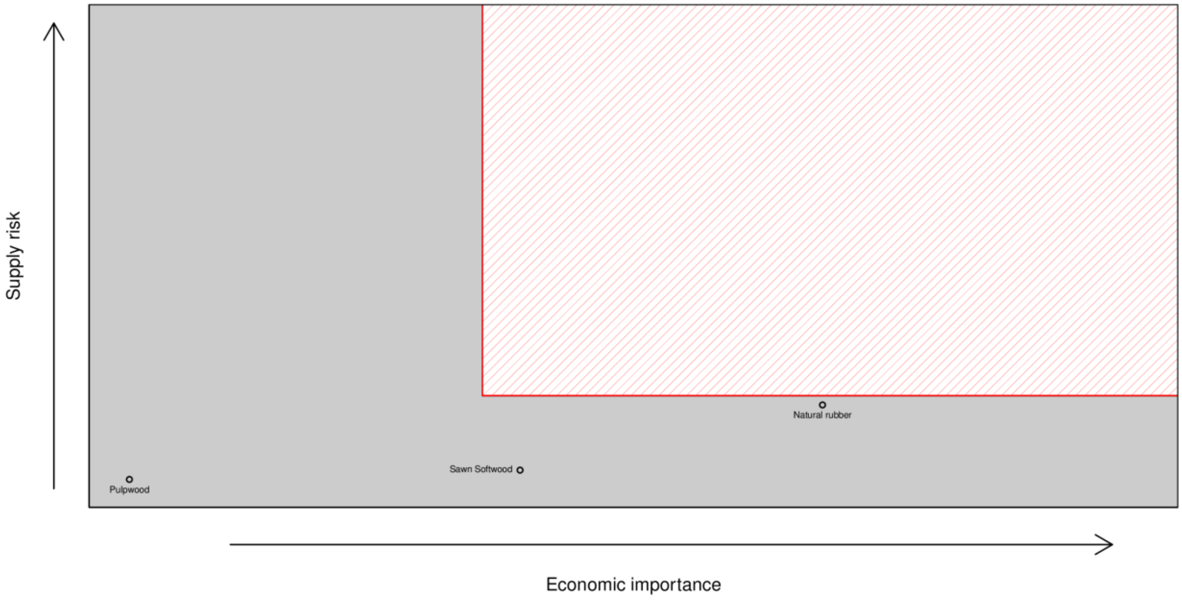
6.4 Criticality Analysis of Biotic Materials

The three biotic materials under investigation have been assessed using the same criticality methodology as implemented for abiotic materials. The results for all materials (biotic and abiotic) from this assessment are presented earlier in Section 4. As such, a discussion on the results of biotic materials, as well as the relevance and data availability follows.

6.4.1 Results of the criticality analysis

The results of the criticality analysis for natural rubber, pulpwood and sawn softwood are summarised in Figure 42. None of the three biotic materials under investigation can be classified as critical when leaving the thresholds unchanged.

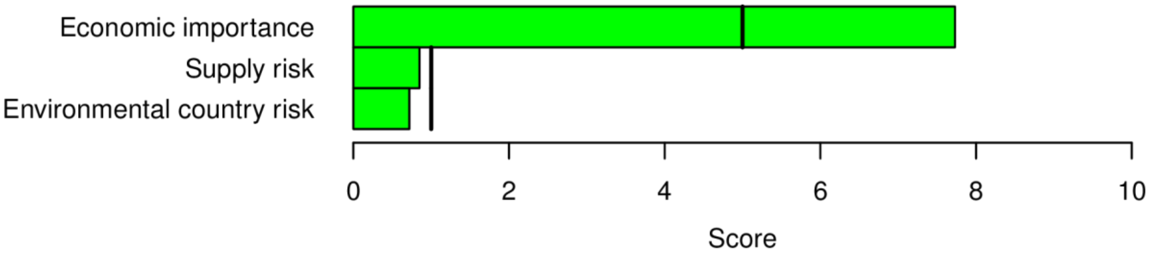
Figure 42: Results of the criticality assessment of biotic materials with world governance indicators



Inspection of Figure 42 reveals that of the three biotic materials, natural rubber is the closest to the critical region as it has both the highest supply risk and economic importance. The results of the analysis for each biotic material are discussed in further detail below.

Natural rubber
In general, natural rubber as a raw material fitted well with the chosen methodology and it has been possible to draw many parallels between the criticality of natural rubber and metals and minerals. Europe is import dependent on natural rubber as it is produced almost exclusively in South East Asia. Additionally, Europe is the second largest consumer of natural rubber after China.

Figure 43: Results of the criticality assessment for natural rubber

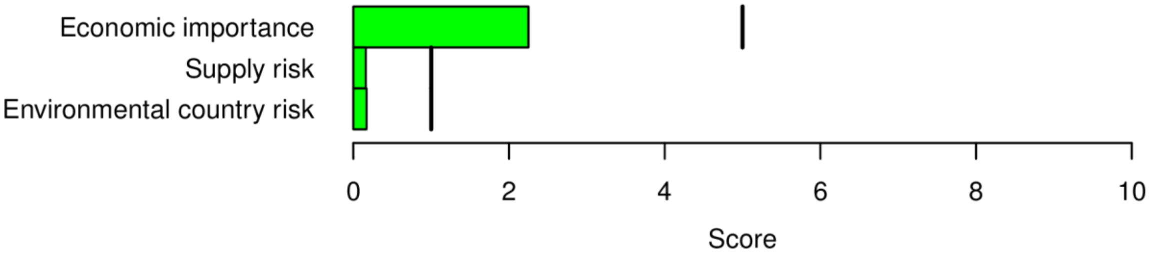


The detailed results of the criticality assessment for natural rubber are shown in Figure 43. The high score for the economic importance of natural rubber is due to its use in tyres for road vehicles. This use falls into the road transport megasector, which is one of the largest megasectors in Europe surpassed only by metals, mechanical equipment and food in terms of gross value added. Tyres account for around 75% of the use of natural rubber in Europe, with the majority of this for road transport. For comparison with abiotic materials, the economic importance for natural rubber is of a similar size to that for aluminium, hafnium, manganese, palladium and rhodium.

The risk associated with supply is not in the critical region for natural rubber. Although natural rubber is produced almost exclusively in South East Asia, the concentration of producing countries is not low as there are over ten rubber producing countries worldwide. This methodology does not take into account the effects of the any cartel-like behaviour exhibited by the alliance formed of Thailand, Malaysia and Indonesia as described by stakeholders. However, the supply risk is increased when taking recycling and substitutability into consideration. Closed-loop recycling of natural rubber from tyres is not technically feasible. At present there is no substitute for natural rubber in tyres which can match the same performance. Therefore the lack of substitutability increased the supply risk. For comparison with abiotic materials, in terms of supply risk natural rubber falls in the same region as tin, hafnium and vanadium.

Pulpwood
Detailed results for the criticality analysis of pulpwood are shown in Figure 44.

Figure 44: Results of the criticality assessment for pulpwood



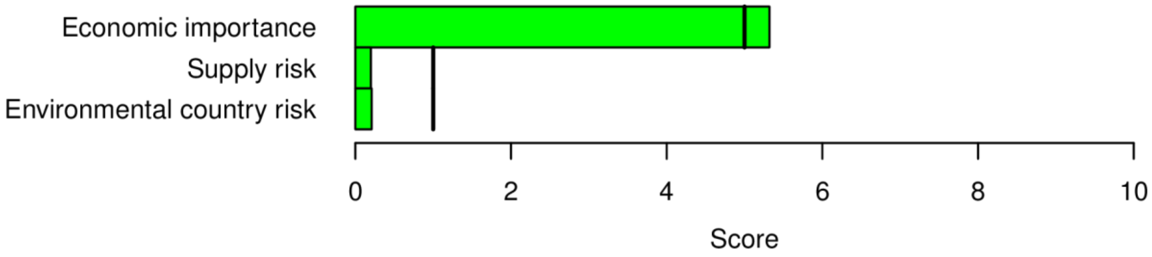
It is evident that as a raw material pulpwood is far from critical, using the current methodology. In contrast to natural rubber, pulpwood is less well suited to this methodology and there are few parallels which can be drawn between the supply risks of pulpwood and those of abiotic materials. Unlike many metals, the majority of pulpwood used by the paper industry in Europe is domestically sourced.

For the economic importance of pulpwood, the only megasector of relevance to Europe is the paper megasector. In terms of gross value added the paper megasector ranks relatively low in comparison to the other megasectors such as mechanical equipment and metals. As a consequence pulpwood has the lowest economic importance of any of the materials in this study.

The risk associated with supply was also determined to be lower than for other materials in this study. As the global production has been used in the assessment, therefore, the concentration of producing countries is very low. However, this is not reflective of the supply of pulpwood used by the European paper industries (though this is true of other materials). In addition the supply risk is further decreased by the contribution from recycling; as post-consumer recycling rates of paper are high in Europe.

Sawn Softwood
Detailed results for the criticality assessment of sawn softwood are shown in Figure 45. Compared to pulpwood, the economic importance and risk associated with supplier are both higher for sawn softwood.

Figure 45: Results of the criticality assessment for sawn softwood



The main uses of sawn softwood are in construction and in the manufacture of furniture; the largest end-sector usage is categorised in the construction materials megasector. The criticality assessment has shown that sawn softwood is more economically important than pulpwood. However, it is of less economic importance than many of the abiotic materials. For comparison with abiotic materials, the economic importance of sawn softwood falls in the same region as titanium, germanium and rare earth elements.

As for pulpwood, the risk associated with supply for sawn softwood is also low and far from the critical region. The supply risk is low as the concentration of producing countries is very low, as sawn softwood is produced in many countries throughout the world. However, as with pulpwood this is not reflective of the supply of sawn softwood used by European industries. Additionally, a proportion of supply is met from recycled wood.

6.4.2 Availability and quality of data

One of the fundamental challenges faced when assessing the criticality of a large range of raw materials is the availability and quality of data. The issues faced with data quality and availability for the three biotic materials is discussed below.

Natural rubber
For quantifying the risks associated with supply, detailed production data for natural rubber was found to be readily available and of sufficient quality. Production data from FAO STAT was employed in the criticality analysis. This data was used to determine the concentration of producing countries and the level of governance of the producing countries.

The two remaining factors for assessing the supply risks, namely the extent to which the material can be substituted and the contribution of recycling, were evaluated with assistance from the ETRMA and its members. At present it is not possible to fully substitute natural rubber in tyre applications. Synthetic rubber is an alternative and a supplement to natural rubber, but it cannot match the performance of natural rubber. The lack of viable substitutes has increased the supply risk associated with natural rubber as a raw material.

In contrast to metals, closed-loop recycling is not technically feasible for natural rubber. Vulcanised natural rubber from tyres cannot be recovered as natural rubber for use in tyres. Instead, rubber material is recovered from tyres as a granulate and used in general rubber goods applications such as synthetic turf, road surfacing and floor tiles. However, the use of this rubber product in some cases will prevent the need to virgin natural rubber being used in an application. It has been possible to estimate a recycling input rate for natural rubber from data on tyre recycling. But, as this is not a closed-loop process and the product cannot be used in place of virgin rubber for the most important applications, a 0% recycling input rate was used in the criticality analysis.

For the existing criticality methodology end-sector usage data are required for investigating the risks associated with the economic importance of a raw material. For natural rubber, the most significant end-user is tyres for automotive applications. The tyre industry uses up to 75% of natural rubber in the EU.[a] It has been possible to acquire detailed end-sector usage data for different tyre applications. Natural rubber is also used in a wide range of both industrial and consumer products; these have been categorised under the rubber, plastic and glass megasector.

Pulpwood

Detailed global production data was found to be readily available for pulpwood for paper from both Eurostat and FAO STAT. In contrast to natural rubber and most metals studied, Europe is not import dependent on pulpwood for the paper industry. However, the methodology developed for abiotic materials uses global production data. To remain consistent with abiotic materials, global production data for pulpwood has been employed in the criticality assessment although this not representative of pulpwood consumed by industries in Europe, though the same is true of many materials, and global figures are used to allow assessment of the whole market.

Recycling data for different paper and board products was readily available. A high recycling input rate has currently been achieved for pulpwood, thus minimising any supply risks. However, at present there are few economically viable and technically feasible substitutes for pulpwood in the production of paper and card.

Sawn Softwood

As for pulpwood, detailed global production data for sawn softwood was found to be readily available and of sufficient quality. However, the same problem arises as to the suitability of using global production data when in fact Europe is not import depend on this raw material. If the necessary data is available it is proposed that the criticality should be assessed, as a sensitivity analysis, using production data for the countries that supply sawn softwood to Europe.

As wood waste arises from many different sectors, recycling input rates which relate to wood at the commodity and species level are not available. The types of wood wastes collected vary from sawdust to furniture to pallets. For assessing the supply risks associated with sawn softwood a value based on the overall wood material recovery rate for Europe in 2010 has been used.[b]

By far the largest hindrance to conducting the criticality analysis for sawn softwood has been the availability of end-sector usage data. This type of data is not frequently collected and as such no recent data at the European level has been found. End sector usage data for a small selection of individual countries was obtained but were not up-to-date and therefore not suitable for the present study. Following stakeholder input and review of data at country level, estimates of end-sector use were developed for use in the criticality assessment.

---

[a] ETRMA (2012), European Tyre & Rubber Statistics.

[b] U. Mantau, commissioned by CEPI Confederation of European Paper Industries and CEI-Bois European Confederation of Woodworking Industries (2012), Wood Flows in Europe.

6.5 Influences on Criticality

At the high level, it has been shown that the criticality methodology employed is applicable for both biotic and abiotic materials. However, there are of course additional influences on criticality for biotic materials which the methodology overlooks. In most instances these will be too specific and not appropriate for the current study, as there is a need to maintain the balance between achieving detail for both biotic and abiotic materials whilst providing an overall view of raw materials. But where there is evidence to prove that any of the additional factors have significant influence on the supply or economic importance of a material they should be considered for inclusion in the methodology for future studies. Additional information on these influences is provided below and in the materials profiles.

All of the influences on criticality discussed below may have an effect on the supply risk of biotic materials. No specific influences on the economic importance of biotic materials have been identified, though price volatility is discussed more generally in Section 5.5.1. Threats to the supply of biotic materials include competition for land use, intensity of resource use, change in climatic conditions, pathogens and competition for other end-uses. Whilst important for biotic materials, many of these issues may be better suited to commentary on the materials. These factors are discussed individually below and recommendations are made based upon issues such as objectivity, data availability and applicability to the analysis. In addition, company concentration may also be relevant for certain materials; this is discussed with a focus on abiotic materials in Section 5.3.2, however a similar approach could be taken here.

The cultivation of feedstocks for biofuel can have both a direct and an in-direct effect on the supply for biotic materials for materials usage. If biofuels are produced from the same crop as used for materials, then there is direct competition between the uses, for example wood or soybeans. If a biofuel feedstock is cultivated on land which would otherwise be used for a material or food/feed crop, there will be an in-direct effect on the supply of crops for materials use. In this report the in-direct and direct effects are treated separately as competition for end-use and competition for land use. The majority of literature in this area is attributed to the competition between energy and food crops; however, it is possible to draw parallels to crops cultivated for materials usage. It should also be noted that not all feedstocks for biofuel will affect the production of groups for food or materials usage, for example where waste streams and by-products are used.

6.5.1 Competition for land use

Competition for land use is of particular relevance to biotic materials where the use of arable land faces competition from food and energy crops. The cost-benefit ratio often determines the outcome of land use competition. However, financial incentives, governmental support for special biomass production and agricultural production standards can all influence the cost-benefit ratio of agricultural land use.[a] In summary land use is both a complex and important issue.

In some countries there is intense competition for land use between agricultural and forest land, which can lead to large areas of forest being converted. Again this competition is fuelled by the promise of higher returns on agricultural crops. Political and socioeconomic factors play an important role when considering competition for land use. Consequently, it is best considered at the country level. This will to a certain extent ensure that the correct climatic conditions are present, for cultivating the biotic raw materials in focus.

For natural rubber the competition for plantations to be used for alternative higher yielding crops is a significant threat to supply. In many natural rubber producing countries, palm oil plantations are replacing rubber tree plantations, partly because the process of palm seasons is less labour intensive.

---

[a] U.S. Department of Energy Biomass Program (2011), Land-use change and bioenergy.

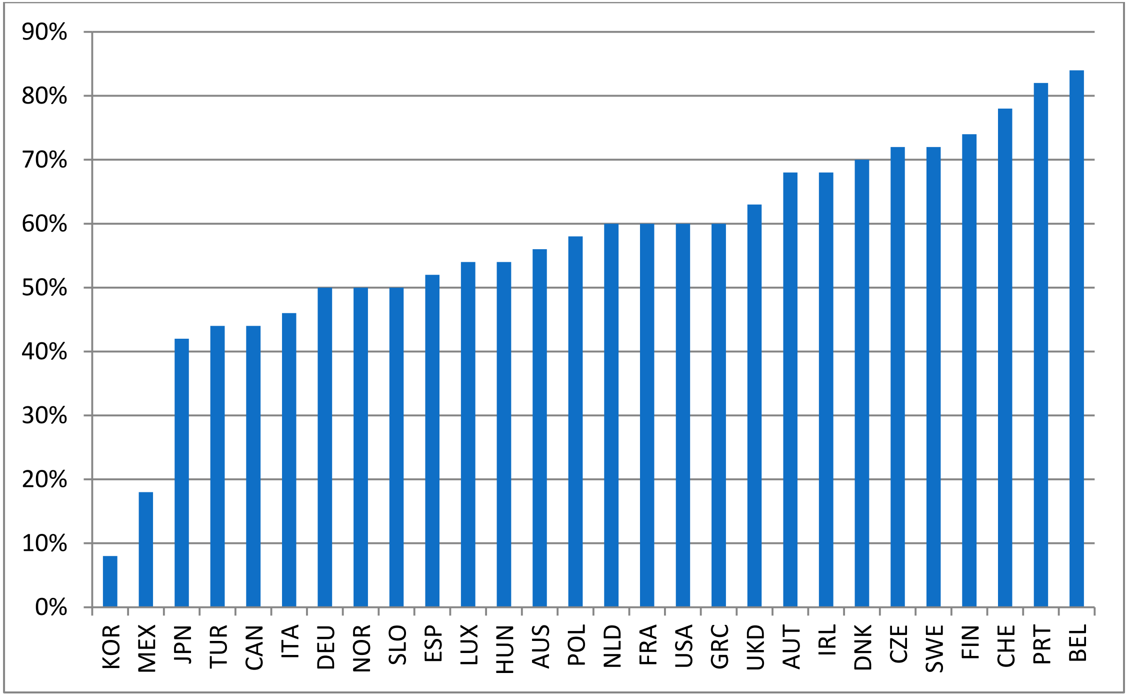
When rubber prices are low plantations and growers are most likely to cut down their rubber trees and switch to a more profitable crop.

Issues surrounding land use are also of concern for the supply of metals and minerals, and as such it is discussed in Section 5.2.2 of this report, though this focuses on EU aspects. The data required for a quantitative assessment of the impact of land use competition for all biotic materials is not readily available. Therefore, the influence on criticality which arises from the direct competition for land use is better suited to the commentary on materials which it affects. From an environmental perspective, land use is the critical issue for any additional cultivation of biomass, whether it is for fuel, food or materials usage.[a]

6.5.2 Intensity of resource use

Unlike abiotic materials, biotic materials are not acquired from a finite source and biotic resources regenerate over time. Consequently, the management of biotic resources has an impact on their availability and supply. One of the main challenges in sustainably managing forest resources is avoiding overexploitation. Increasing intensity of forest resource through overexploitation can lead to deforestation. The same principles also apply to the management of rubber plantations and agricultural crops. Through overexploitation of a biotic resource, it may not be possible to maintain an adequate supply, potentially leading to future supply shortages.

Figure 46: OECD indicator for intensity of forest use by country.



The OECD has developed an indicator which assesses the intensity of use of forest resources. It achieves this by relating data for actual harvest of timber to annual productive capacity.[b] This indicator is presented as a percentage and can be ranked by producing country; it addresses overexploitation and degradation, which are the main challenges to ensuring sustainable management of forest resources. The intensity of resource use could be used as an alternative indicator for assessing the supply risks of biotic materials during future criticality studies. Figure 46 shows the harvest as a percentage of annual

---

[a] Oeko-Institute (2011), Deliverable 5.3: Report on challenges and conflict areas for non-food crop production systems, Crops 2 Industry Project.

[b] OECD Environment Directorate (2008), OECD Key Environmental Indicators.

growth for a range of countries, it shows that there is significant variation with the intensity of forest resources within Europe.

This methodology could be used to assess the intensity of resource use of other biotic raw materials directly. The intensity of resource use will have a direct impact on the supply risk of the material from a particular country, with past years drawn to assess trends. However, for biotic materials such as natural rubber where the majority is produced by small holders, it may not be possible to model production capacity. Rubber plantations in South East Asia are dominated by smallholders with small scales of production, typically cultivating areas of four hectares or less.[b]

In conclusion, it would be relatively straight forward to include an indicator for intensity of use into the current methodology for wood. Countries with greater intensity of use of resources, will exhibit a greater supply risk, as the supply is less sustainable. However, it would be challenging to assess this indicator for other biotic materials owing to a lack of available data. Therefore it should not be included in the methodology and instead should be discussed in the commentary on materials.

6.5.3 Biodiversity

Changes in land use and cover through forestation and cultivation of crops can lead to alterations in species populations and dynamics. Therefore, the protection of biodiversity is of key concern when considering the environmental impacts of crop cultivation. The level of biodiversity is of particular importance to good forestry management, as poor practices can lead to forest degradation and a permanent loss in biodiversity. The risk of adverse effects arising from a change in biodiversity will be strongly dependent on location, agricultural and forestry practices, previous and indirect land-use and the downstream processing method employed.[a] However, changes in biodiversity in strict terms are not a risk opposing the supply of biotic raw materials, but more an adverse environmental impact associated with cultivation of biomass for materials (and other) usage.

A significant volume of literature is available on protecting biodiversity and risk mitigation strategies. An alternative environmental indicator could be to assess the degree of biodiversity in a producing country. The OECD has developed an environmental indicator which evaluates the share of threatened or extinct species as a total of the known species in a country. However, this is beyond the scope of the current high level assessment in spite of importance to the sustainable management of biotic resources.

6.5.4 Climatic conditions and natural disasters

Climate change and natural disasters can severely affect the production of biotic materials. Climate change will affect the productivity of crops and land use; however, these interactions are intricate and not well understood. In summary, changes in climate and natural disasters are a risk to supply for biotic materials.

For example in 2009 severe droughts on the Indochina peninsula coupled with heavy rains during the tapping season in Indonesia led to the production of natural rubber being lowered by 5%. As rubber trees originate from tropical rain forest, high levels of moisture and rain are a requirement of their cultivation.[b] However, an increase in rainfall can also lead to a decrease in tapping days per year. Drought causes a reduction in photosynthesis followed by reduced growth of young rubber plants. As maximum and minimum temperatures and annual rainfall change in the region where rubber is cultivated, it is anticipated that the rubber yield will decrease.[c]

---

[a] http://www.crops2industry.eu/index.html accessed September 2013

[b] S. Sdoodee and S. Rongsawat, 2012 International and National Conference for the Sustainable Community Development of Local Community: The Foundation of Development in the ASEAN Economic Community (2012), Impact of climate change on smallholders' rubber production in Songkhla Province, Southern Thailand,

[c] Special Issue on Climate Change, Natural Rubber Research, volume 24, number 1, 2011.

Several studies have been conducted on the impact of climate change and natural disasters on rubber cultivation. However, these studies are limited to one country or region of a country and therefore do not provide an overview of the impact on rubber production. It is evident that there are many influences to the supply of rubber which may arise from climate change and natural disasters. However, these influences are complicated and not easily quantified and as such should be considered beyond the scope of the present study. Again this influence on criticality may be better suited to a more forward looking study of materials criticality.

Forests are also severely affected by climate change. Storms, snow, hail and droughts have been known to have a significant impact on industrial roundwood production, as they alter or even halt the normal conditions for forest management and forestry.[a]

Although important to supply, within the current methodology it is not possible to quantify the effect on climatic conditions on the supply of biotic raw materials at present. This risk to supply cannot be assessed as part of the existing methodology and is best discussed in the general commentary on raw materials.

6.5.5 Competition for use from energy and food

In the current study the focus is on materials usage for raw materials and for abiotic raw materials; this is the sole use. In contrast many biotic materials, such as soya beans and palm oil, can also be used for energy and food/feed. Thus an additional supply risk experienced by biotic materials is the direct competition between these different uses. This supply risk is of particular importance to the woodworking and paper industries where competition from renewable energy sector for wood impacts on the availability and price of the raw material. An increased use of wood products for bioenergy in Europe could reduce the amount of wood available to European paper and woodworking industries, leading in turn to an increased demand for imports. A recent study from the OECD reports that to produce 10% of the world's transport fuel by 2020 would require 26% of the world's current crop output.[b] Unless production increases significantly, increased competition from energy usage is to be expected.

Within Europe there has been strong political support of renewable energies; this has led to competition for the use of renewable raw materials between energy and materials. Within the woodworking industries there is a fear that the increasing use of forest products for bioenergy, will lead to an increase in price of wood.

As part of their research on the use of biomass in the EU Countries, the Nova Institute have calculated the distribution of use across the three sectors for 25 renewable raw materials in 2007.[c] The results for selected raw materials are shown in Table 33. Natural rubber does not experience any risk from direct competition with energy and food uses. Therefore the criticality of natural rubber will not be affected if completion for use is included within a criticality assessment.

---

[a] Sustainable timber production in a changing climate, Future Forest Good Practice Guide, http://www.futureforest.eu/uploads/timber_production_guide

[b] Ronald Steenblik, OECD, presentation at workshop on sustainable biofuels: addressing indirect land use changes, European Parliament (2013), The food vs. fuel debate: support policies, farmland and trade issues,

[c] Nova-Institute (2012), Bio-based Economy in the EU-27: A first quantitative assessment of biomass use in the EU industry.

Table 33: Distribution of use of 5 biotic raw materials in the EU-27 in 2007

Material	**Distribution of use (%)**		
	Materials	**Food/feed**	**Energy**
Cotton (lint)	100	0	0
Maize	10	75	15
Natural Rubber	100	0	0
Soya beans	5	85	10
Oil Palm fruit	30	50	20

Source: Nova-Institute 2012.

By quantifying the distribution of use of a raw material between the three sectors it is possible to quantify a snapshot of the competition between materials, food/feed and energy. It could be used as an additional factor or as an indicator for assessing supply risk, or considering criticality.

An increasing use of woody biomass for energy production is likely to have a direct impact on the way that land and natural resources are used.[a] Attempts to mitigate the problem of displacement of food crops in favour of biofuels may lead to deforestation or the displacement of established wood users. Possible restrictions on the availability of wood for materials use will generate tensions on the feedstock market and represent a significant risk to the supply.

However, the effects of end-use competition on the supply of a biotic material are not well understood. Before it can be considered for inclusion in the criticality framework, further evidence is required which demonstrates the impact it has on supply. In addition it is not clear how this influence on criticality can be assessed quantifiably within the current framework. Data availability for all the biotic materials under consideration may also preclude the study of competition for end-use.

6.5.6 Effect of biological threats on supply

Threats to supply of biotic materials can arise from plant pathogens and pests, as outbreaks can lead to crop degradation and damage and ultimately severe losses of supply. This is particularly a risk for tropical regions, where the relationship between pests and host plants are less well studied and understood.[b]

Although there is sufficient evidence to suggest that they pose a significant threat to supply of biotic raw materials, it is not be possible to include the threat of pathogens and other biological agents as an indicator in the criticality methodology. As the threat is only experienced by biotic materials and not abiotic materials it is too specific for the current high level study. Additionally, it is not clear how it could be developed into a quantifiable indicator. Instead a qualitative judgement of the risk faced by biological threats to each biotic raw material is better suited.

---

[a] Proposal for a Directive of the European parliament and of the council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources, a position paper from EPF, EOS, FEP, FEFPEB, CEI-BOIS, (2009).

[b] M. J. W. Cock, M. Kenis, R. Wittenburg, Forestry Department Food and Agriculture Organization of the United Nations (2003), Biosecurity and Forests: An Introduction with particular emphasis on forest pests,

Case Study: South American Leaf Blight

An example of a pathogen which poses a severe threat to the supply of biotic raw materials is South American Leaf Blight (SALB). The disease has affected the whole of the South American Continent. Infestations of SALB in South America have prevented all commercial rubber plantations from reaching full production as it destroys the trees before they are able to reach full maturity. To date, control measures against the disease including chemical protection, breeding and selection have all been unsuccessful.

South American Leaf Blight (SALB) is of strategic concern to the supply of natural rubber. SALB is a fungal disease, which only affects species within the genus *Hevea* (which includes the rubber tree). It produces spores on the leaves of rubber trees which cause defoliation and dieback. In some cases the plant is significantly weakened and dies. The infection and establishment of SALB requires wet weather, a stable temperature of 22-28°C and young foliage of the rubber tree. The pathogen can survive for over a week on inorganic objects such as clothes, glass, metal or paper. Thus SALB can be spread through non-host materials. The spores can also spread the disease over relatively long distances by wind and rain.

Natural rubber plantations are particularly susceptible given their uniform genetic background and most commercial rubber plantations around the world are descended from seeds originating in Brazil. Resistant varieties of the rubber tree are not currently available as the pathogen is capable of evolving and breaking down resistance. However, some varieties of the rubber tree are more resistant than others.

At present the disease is restricted to South America, but it has the potential to spread to other rubber producing areas of the world. In South and Central America it prevents the planting of commercial rubber plantations. Strict pest control such as restrictions and regulation's on imports from South America, has kept South East Asia largely free of the disease. However, increased trading and travel has increased the risk of exporting the disease. If the disease were to spread in Asia this could have devastating effects on the supply of natural rubber.[a] A pest risk analysis has been prepared by been prepared by the rubber growing member countries of the Asia and Pacific Plant Protection Commission (APPPC), including Thailand, Indonesia, Malaysia, China and India.[a]

If SALB were to spread to Southeast Asia, it could increase the cost of production whist lowering productivity. As additional disease controls would increase the cost of production, without treatment large areas of rubber plantations would be lost. If a significant area of rubber plantations were to be infected then it could lead to a shortage of rubber as a raw material. As a consequence the economic consequences of an SALB infestation in South East Asia are high, as rubber is a significant economic crop in this region.

6.6 Summary and Conclusions for Biotic Materials

Three biotic materials, natural rubber, pulpwood and sawn softwood, have been assessed using the current criticality framework. The results have shown that none of these materials can be considered critical under the current framework for criticality. Of the three materials in focus, natural rubber was found to be the closest to the criticality thresholds. This is due to its use in tyres for road transport coupled with its lack of suitable substitutes and minimal recycling. In contrast pulpwood and sawn softwood scored lower on the criticality scale, due to higher recycling rates and low concentration of producing countries. The differences in the supply of biotic materials and abiotic materials have been outlined. Following this it was determined that at the high-level of the current assessment, the criticality framework is suitable for both abiotic and biotic materials.

Several issues of data quality and availability for these new materials have been raised, comparable to those faced for the less well reported abiotic materials: notably the use of global production data for wood, when in fact most pulpwood and sawn softwood consumed by European industries is domestically sourced. To remain consistent with the methodology employed for abiotic materials, it was decided that global production data was used for biotic materials. However, for further criticality studies, data permitting, we suggest that only countries which supply wood to Europe could be considered when calculating the supply risk. In comparison to many of the abiotic materials, end-sector usage data for the two wood products selected has been of lower quality and less readily available. With the exception of paper recycling for pulpwood, recycling input rates are not readily available for biotic materials. In many instances closed-loop recycling of biotic raw materials is not technically feasible.

Influences on criticality which affect the supply of biotic raw materials have been discussed. It is recommended that further evidence is required of their effects to supply before they can be considered for inclusion into criticality methodologies of future studies. For biotic materials, the competition for both land use and end-use can potentially pose a significant threat to supply. As such these influences should not be ignored. It is suggested that the effects of competition for end use should be monitored for forestry products, and indeed any other biotic raw materials of interest to the European economy. In addition the effects of biofuel subsidies on the availability and price of wood should also be monitored, as it may affect the supply of wood as a raw material for industries including construction and paper.

By studying the three exemplar materials, natural rubber, pulpwood and soft sawnwood, it has been shown that biotic materials are worthy of further study in the field of criticality. In order to incorporate how some of the specific influences on criticality affect the supply of biotic materials and not that of abiotic materials, a separate criticality framework for biotic materials may be of merit. However, by adopting separate methodologies for biotic and abiotic materials it may not be possible to directly compare their criticality.

It was often found that data of sufficient quality was not readily available for end-sector uses of biotic materials. In comparison to abiotic materials, more work was required to locate the relevant data for biotic materials. Lack of data may preclude the criticality study of some biotic materials. We therefore recommend that better data should be collected for the share of end-sector uses, in particular for forestry products such as industrial roundwood and its commodities. In addition recycling data, where applicable, should also be collected for biotic materials, or applications of biotic materials.

It has been suggested that certification and standards can be used to balance growing demand for raw materials with the environmental impacts of cultivating them. Such standards and certification should aim to promote sustainable management of raw materials. Standards can help major consumers of raw materials commit to procuring sustainably grown biotic raw materials. The International Rubber Study Group recently announced that they aim to set up a voluntary certification program and standards for sustainable natural rubber.[a] Certification schemes and standards are already in place for the sustainable management of forestry products.

In a further study, a broader range of biotic materials should be investigated. The scope could be extended to include biomass crops which are not used directly as materials, for example those which are cultivated for substances or building blocks for chemical synthesis. Examples of these include the use of starch for additives or the use of ethanol produced from crops for producing plastics. The European chemical industries use a wide range of biotic materials as feedstocks for synthesis. The materials used range from vegetable oils such as palm and soy, to starches such maize and to medicinal plants used by the pharmaceutical industry. A list of further biotic materials which could be included as part of a further study are listed in Sections 6.1 and 6.2.

---

[a] http://www.environmentalleader.com/2013/09/04/rubber-industry-to-create-sustainability-standards/ accessed September 2013.

7 Suggested Actions

The recommendations set out below are those of the author(s) and do not necessarily reflect the official opinion of the Commission.

7.1 Suggestions to the European Commission

- The revised list of twenty one critical raw materials for the EU should supersede the existing list of fourteen materials, and be used in place where practicable.
- It is important that the results and findings are disseminated; however, it is suggested that this should be accompanied by guidance on the intended purpose of the list and by analysis to avoid misinterpretation.
- Non-critical raw materials should not be disregarded from resulting actions; however, specific actions may be appropriate for the critical materials given the combination of their economic importance and supply risk.
- The results of this study should link with, and be used to inform, on-going EC programmes such as the European Innovation Partnership on Raw Materials, the EU/Japan/US Tri-lateral dialogue, and work towards harmonising EU minerals inventory data. The study should also tie into up-coming work in related areas, such as competitiveness, material flow analyses, and materials traceability and stewardship schemes.
- Raw materials and materials criticality should be integrated into aligned areas of EU policy, for example the flagship initiatives of the Europe 2020 Strategy 'an Industrial Policy for the Globalization Era', 'Innovation Union' and 'Resource Efficient Europe', and Directives such as those related to Mining Waste, End of Life Vehicles, Waste Electrical and Electronic Equipment, and Batteries, as well as the Waste Framework Directive. This process could involve dialogues between policy makers, industry and expert groups.
- On-going dialogue should be maintained with other relevant DGs that have on-going work on critical raw materials (e.g. DG Environment, DG Trade, DG Research, JRC Institute for the Environmental and Sustainability, JRC Institute for Energy and Transport), as well as Member States, industry organisations, and other expert groups.

7.2 Suggestions for Future Studies

The following recommendations are made for consequent studies, following on from this exercise:

- It is recommended that the EU list of critical raw materials continues to be regularly updated at three yearly intervals.
- The Ad-Hoc Working Group should remain in place, maintaining a similar size and remit by providing input and ensuring the needs of industry are met. Appointment of additional members from upstream sectors is suggested, provided there is no impact on the Group's function.
- The following are proposed in relation to the scope of materials:
  - The scope of materials included should remain in principle focused on non-energy, non-food raw materials.
  - The list of candidate materials used for the analysis should be reviewed for the next exercise to ensure it remains appropriate for the purpose of the study. This may lead to new materials being included or others removed.
  - A wider range of biotic materials could be considered, either within the same framework or separately depending on the requirements of the EC and EU. Further detail is provided in Section 6.6.
- Modifications to the quantitative methodology are reviewed and carefully considered. These include adjusting the thresholds, allowing for gradations in criticality, and changes to the handling of substitution. These are outlined in detail in Annex H.

- Inclusion of additional indicators to the quantitative methodology could add greater richness to the analysis. Two indicators have been proposed for consideration: company concentration and price volatility. These are outlined in detail in Annex H.
- It is recommended that the refinements suggested in Annex H, together with others that may be raised, are considered by the Ad-Hoc Working Group soon after the publication of this study and, if necessary, a revised methodology could be set prior to the next exercise. Any changes adopted should require comprehensive justification.
- While data quality has been increased in this study, areas remain where improvement can be made - specifically: end-use data (particularly for alloying metals and wood); data for end of life recycling rates (which still relies mostly on a single source), improved production data (particularly for some industrial minerals) and substitution.

7.3 Suggestions for Actions Relating to Critical Raw Materials

- Resources and reserves of critical and other raw materials in the EU and linked countries could be identified more clearly and exploitation assessed: for instance, deposits of antimony (Italy), borates (Serbia (non-EU), chromite (Albania), lithium (Serbia non-EU), PGMs (Finland), REEs (Sweden, Greenland), and tungsten (Portugal, UK). This could also include secondary resources such as tailings and spoilings heaps. Where appropriate, approaches for further development of these resources can be identified.
- The internal EU flow of critical raw materials could be modelled and/or characterised in detail. For instance internal supply, capacity, imports and exports of different grades of materials, and the supply chain stage materials that are required in the EU could be assessed. This will form a richer picture of which materials have significant indigenous supply that could be used to support the market, and which materials require large import from Third countries and at what stage of the value chain.
- Furthermore, many EU industries are reliant on the critical raw materials, but are distanced from issues of primary supply. This includes manufacturers, designers and waste processors. Increasing awareness amongst these actors is necessary, leading to changes in practice. For example, product designers could consider alternative materials in their designs or develop products that enable activities such as recycling and remanufacturing.
- The EU is likely to remain reliant on Third countries for supply of the critical raw materials. Existing and new diplomacy and trade agreements, such as the EC raw materials diplomacy events, could be used to ensure continuing access. This is particularly relevant for materials such as beryllium, coking coal, magnesium, natural graphite and niobium.
- Appropriate resource efficiency and recycling actions could be identified and progressed, with incentives provided where appropriate. These actions could be linked to initiatives such as enabling the circular economy. For example:
  - High recycling levels linked to certain applications are possible, for example tungsten carbide tooling (cobalt and tungsten), batteries, electronic and electrical equipment, phosphate in run-off and sewage.
  - Where materials are widely used in dispersive applications (such as chromium, fluorspar, magnesium, niobium, REEs and tungsten), better sorting, separation and recovery strategies could be investigated and developed where appropriate. For example, machining closer to smelters and casters could improve recycling rates.
  - Substitution and dematerialisation at an application-level remains a valid and important option for many critical raw materials, for example heavy rare earth elements, indium, graphite and magnesite, or the use of nanostructured alternative materials. Existing actions related to this could continue, and the new list of critical raw materials considered where possible.
  - The potential for other resource efficiency actions such as remanufacturing and re-use could be explored to determine the impact on critical raw material use and where these strategies might be appropriate.
- A critical raw materials or by-products Special Interest Group could be formed within the International Metals Study Groups, acting as a flexible horizontal group across these organisations.

- Actions could be prioritised where a combination of improvement in environmental performance and supply of critical raw materials can be made (such as reprocessing of tailings).

7.4 Suggestions for Actions Relating to Biotic Raw Materials

- Any follow on study in this area, whichever approach is taken, could include a wider range of biotic materials to allow broader comparison between these materials and abiotic materials.
- Data quality will be an on-going issue and input from trade organisations and industry is required to ensure the relevant data is made available.
- Indigenous EU supply of certain materials such as wood is significant, compared to the abiotic materials; therefore these materials may require special treatment.

7.5 Other Suggested Actions

- Develop an improved environment for EU raw materials supply to improve EU raw materials governance and to set a baseline for Third countries through the EIP and other platforms. It is recommended to establish links with the future coordination and support action under Horizon 2020 in which the concept of deposits of public importance will be explored.
- Third countries are essential for supply across all raw materials; therefore it is essential to establish diplomatic dialogues with countries that are significant suppliers across all materials.
- Continue to pursue issues over trade restrictions and their impact at relevant international fora, such as the WTO.
- There are linkages between stewardship/traceability and material criticality activities. The EITI, voluntary certification schemes and mining governance indices could be supported and expanded, benefiting both areas. Analogous schemes and linkages for biotic materials also exist, such as the sustainable management of forests.
- Develop a greater awareness of raw materials issues along values chains, and engage users of (critical) raw materials through industry groups to develop appropriate action plans; for example, end-user investment or joint ventures for developing primary supply or refining. The involvement of SMEs could be a requirement of this action. The existing industry group in Germany could be examined as an exemplar.
- Discuss the availability of detailed trade statistics for the raw materials with Eurostat. Trade data for individual materials are not always available. Separation of materials in trade classifications is suggested to provide more detail for some of the speciality materials.
- Initial results comparing mining and refining supply risks indicate that there can be substantial differences between the two. These differences will extend further along supply chains. Therefore an application based supply chain analysis could be conducted, taking into account other risks such as processing, manufacturing, corporate concentration for each stage, to identify how raw materials risks compare with other risks along the supply chain. For example, this could be conducted for the wind turbine industry or similar low carbon technology through the JRC.
- Improve geological knowledge, specifically improved characterisation of by-products/co-products in base metal deposits and other sources.

Annex A – Members of the EU Ad-Hoc Working Group on Raw Materials

Organisation	Member
BGRM	Patrice Christmann
BGRM	Anne-Sophie Audion
BGS	Andrew Gunn
Eurogypsum	Christine Marlet
Eurometaux	Annick Carpentier
Umicore	Christian Hagelüken
Tin Association	Kay Nimmo
Euromines	Corina Hebestreit
Euromines	Johannes Drielsma
Geological Survey of Sweden	Kaj Lax
Hungarian Office for Mining and Geology	Tamas Hamor
	Kertesz Botond
Industrial Minerals Association	Dr Michelle Wyart- Remy
Industrial Minerals Association	Sonia Clarena Baron
University of Augsburg	Armin Reller
BMWFJ, Austria	Robert Holnsteiner
Montana University of Leoben, Austria	Prof.Dipl.-Ing. Dr. Manfred Mont Hoscher
Ministry of Industry and Trade of the Czech Republic	Pavel Kavina
France - Direction générale de l'Energie et du Climat	Adeline Morliere
Germany - BGR	Antje Wittenberg
Germany - BMWI	Peer Hoth
Euroalliage	Inès Van Lierde
Netherlands' Environmental Assessment Agency	Ton Manders
Portugal	Prof. Leite Machado
Portugal-DGEG	Prof. António Mateus
Eurofer	Aurelio Braconi
European Tyre & Rubber Manufacturers Assoc.	Fazilet Cinaralp
CEI-BOIS AISBL	Philip Buisseret
NGU - Geological Survey of Norway	Rognvald Boyd
	Danilo Bonato
EGS	Nikos Arvantidis
EGS	Luca Demicheli
ACEA	Peter Kunze
International Study Groups	Don Smale
International Study Groups	Paul White
Nokia	Salla Ahonen
CEFIC	Antonia Morales Perez
The Cobalt Development Institute	David Weight
The Cobalt Development Institute	Brigitte Amoruso
UNCTAD	Alexei Mojarov

Representatives from the European Commission:

DG Enterprise and Industry	Mattia Pellegrini, Flor Diaz Pulido, Alexis Van Maercke, Malwina Nowakowska, Milan Grohol, Maria Spiliopoulou-Kaparia, Joao Aguiar-Machado, Paul Anciaux, James Copping, Guglielmo Di Cola, Cinzia Giaconia, Michal Kubicki
DG Trade	Caroline Boeshertz, Ivone Kaizeler, Rein Nieland
DG JRC - IET	Efstathios Peteves, Raymond Moss, Evangelos Tzimas
DG JRC - IES	David Pennington, Lucia Mancini
BEPA	Dr Pierre Dechamps
ECHA	Anja Hlade
EDA	Inge Ceuppens, Michael Simm
EESC	Dumitru Fornea, Maria José Lopez Garcia, Jonathan Peel
EUROSTAT	Christian Heidorn
DEVCO	Mariusz Tamborski
DG EMPL	Antonis Angelidis

Attendees from project team:

- Oakdene Hollins: Adrian Chapman, Josephine Arendorf, Tecla Castella, Nick Morley, and Peter Willis
- Fraunhofer ISI: Luis Tercero Espinoza, Eva Wichmann

Annex B – Description of EU Criticality Methodology

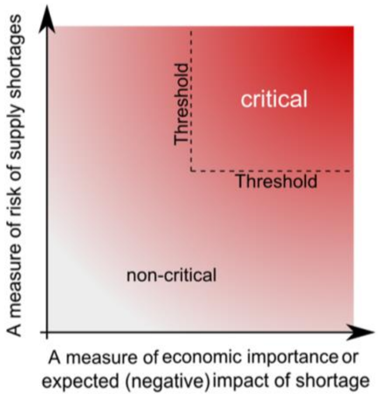
The EU materials criticality methodology was previously developed by the Ad-hoc Working Group on Critical Raw Materials, drawing on the expertise of the Group and other sources.[a,b] The methodology uses a combination of three indicators to assess criticality:

- Economic importance
- Supply risk (linked to poor governance)
- Environmental country risk (supply risk linked to low environmental standards)

For the materials in consideration each is assessed individually, using a combination of factors to produce a value for these three indicators. This methodology uses a top down approach, capturing all the uses and production of the materials, and encompassing the whole of the EU economy.

The combination of the results for economic importance and supply risk leads to two, two-dimensional depictions (one for supply risks due to poor governance and one for risks due to low environmental standards) (Figure 47). This then provides a relative ranking of the materials, with those closest to the top right hand corner, above the defined thresholds for both axes, designated as critical raw materials.

Figure 47: General scheme of the criticality concept projected into two dimensions.



Source: Sievers, Henrike; Buijs, Bram; Tercero Espinoza, Luis A. (2012): Limits to the critical raw materials approach. In: Proceedings of the ICE - Waste and Resource Management 165 (4), 201–208.

A material was considered critical to the EU if it was found to be in the critical region when either the supply risk or environmental country risk is assessed. Thresholds for the indicators were set by the previous AHWG based on the requirements of the exercise. These are set at 5 for economic importance and 1 for both of the supply risk measures. The measurement of the indicators is described below.

Economic importance

Because the value of a raw material to the economy far surpasses the value of the raw material itself, the economic importance of materials may be better assessed by the value of the products that depend on these. A pragmatic way to do this, as proposed by the AHWG, is to identify the end-uses for each raw material in addition to the corresponding % of net demand (distribution of end uses). In a second step, each end-use is assigned to a “megasector”, defined by a collection of related NACE sectors at the three and four digit level (Table 34). The assignment is made as far down the value chain as possible. The value of each megasector is accounted for in terms of gross value added, as published by EUROSTAT in the Structural Business Statistics database (see Annex C for more details). The end use structure is combined

---

[a] Critical Raw Materials for the EU, (2010), European Commission

[b] For example see; Assessing the long-term supply risks for mineral raw materials—a combined evaluation of past and future trends, 2009, Resources Policy 34 pp 161–175

with the corresponding megasectors' Gross Value Added (GVA) to yield the economic importance (unscaled).

Table 34: Summary of "megasectors" used in the calculation of economic importance. This aggregation of sectors was developed by DG ENTR for the original EU criticality assessment.

Megasector	Short description
Aeronautics, trains, ships	Ships and boats, railway, tramway locomotives, rolling stock, aircraft and spacecraft.
Beverages	Beverage industry in general (not agriculture).
Chemicals	Production of organic and inorganic chemicals.
Construction material	Ceramic tiles, bricks, concrete, cement, plaster, building stone, metal structures and parts of structures, builders, carpentry and joinery of metal, ceramic household and ornamental articles, etc.
Electrical equipment	Electric motors, generators and transformers, electricity distribution and control apparatus, insulated wire and cable, lighting equipment and electric lamps, household electrical equipment.
Electronics & ICT	Office machinery and computers, accumulators, primary cells and batteries, electronic components, television, radio transmitters and sound or video equipment, telephony, medical equipment, industrial process control equipment, optical instruments, etc.
Food	Food processing in general (not agriculture).
Mechanical equipment	Mechanical power equipment (except aircraft, vehicle and cycle engines) including e.g. engines and turbines, pumps and compressors, taps and valves, driving elements, non-domestic cooling and ventilation equipment, machine tools, machinery for diverse purposes and non-electric domestic appliances.
Metals	Smelting and refining of ferrous and non-ferrous metals, including casting and shaping into containers, wiring, etc., powder metallurgy, treatment and coating of metals, recycling of metal waste and scrap.
Mining of metal ores	Ferrous and non-ferrous metals.
Other final consumer goods	Furniture, cutlery, tools and general hardware, tools, locks and hinges, musical instruments, sports goods, games and toys, jewellery and related articles, coins.
Paper	Pulp, paper and paperboard, corrugated paper and paperboard and of containers of paper and paperboard, household and sanitary goods, paper stationary, wall paper.
Plastic, glass, rubber	Rubber tyres and tubes, other rubber products plastic plates, sheets, tubes and profiles, plastic packing goods, flat & hollow glass, glass fibres, technical glassware, abrasive products.
Pharmaceuticals	Pharmaceuticals in general, including preparations for dentistry.
Refining	Refining of petroleum and processing of nuclear fuel.
Road transport	Agricultural tractors, electrical equipment for engines and vehicles, motor vehicles, trailers and semitrailers, parts and accessories for motor vehicles, motorcycles and bicycles.

To calculate the economic importance the share of demand of a raw material in a sector is denoted A_s, and the value of the corresponding using megasector is denoted by Q_s. The relative economic importance of the raw material, EI, can then be aggregated by

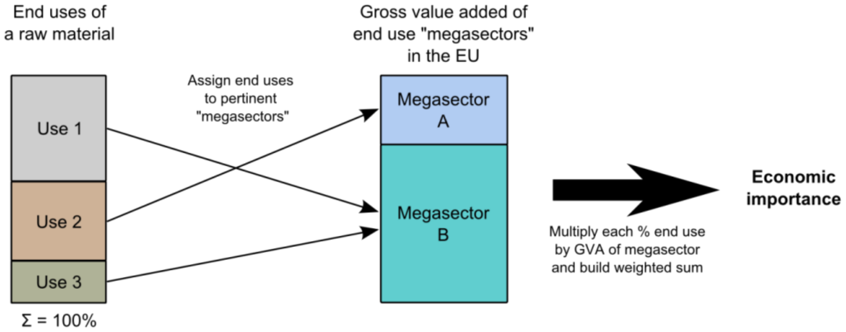
Equation 3: Calculation of economic importance (before scaling)

$$EI = \sum_{s} A_s Q_s$$

Note that $\sum A_s = 1$ because the analysis encompasses all uses of the raw material. This calculation means that the economic importance is the weighted sum of the gross value added of the megasectors consuming a given raw material, using the share of demand in each megasector as the weight of the megasector in the sum. Therefore, the quantity EI seeks to characterize the economic impact of a sudden supply stop, assuming this leads to a complete stop of production in the affected megasectors.

While this is an overestimation, the Working Group deemed this to be the most pragmatic way of assessing economic impact in face of the data limitations. This procedure is visualized in Figure 48.

Figure 48: Visualization of the compound indicator for economic importance. GVA = Gross value added obtained from EUROSTAT's Structural Business Statistics for the EU27.



Source: Fraunhofer ISI.

Because the criticality exercise is relative, not the absolute numbers but the relative ranking of the different raw materials is important. Therefore, the values yielded by Equation 1 were scaled to fit in the range 0-10, where 10 corresponds to the maximum possible economic importance following this method in a given year.

Supply risks

The risks in supply are considered to arise from a combination of several factors, namely:

- lack of substitutes
- low recycling rates
- high concentration of producing countries (primary production) combined with either
  a. poor governance as measured by the World Governance Indicators (WGI), or
  b. low environmental standards of the producing countries as expressed by the Environmental Performance Index (EPI).

These four elements are brought together into a single indicator, denoted SR and calculated for poor governance, Equation 4

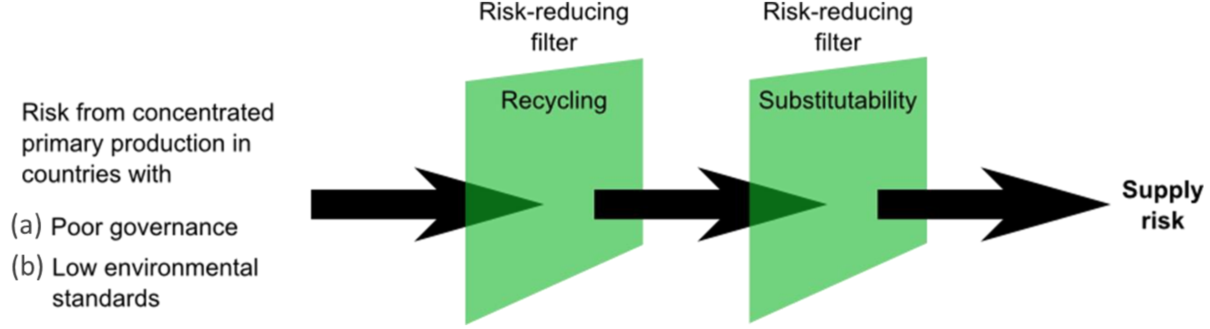
Equation 4: Calculation of supply risk (based on World Governance Indicators)

$$SR = \sigma(1-\rho)HHI_{WGI}$$

Where σ accounts for the substitutability of the raw material, ρ is the fraction of demand that is currently met by recycling, and HHI_{WGI} simultaneously characterizes the concentration of production at the country level and the governance in those countries. The interplay of these individual elements to yield a composite indicator for supply risk is graphically shown in Figure 49.

The three components are explained in more detail below. However it is important to note that according to this methodology, low substitutability and recycling rates as well as concentration of production in few countries with poor governance, all increase the supply risks. Thus, it is not possible to see which combination of factors led to a particular result without considering the components of the calculation separately.

Figure 49: Visualisation of the compound indicator for supply risk as defined by the Ad-hoc Working Group on defining Critical Raw Materials (2010)



Source: Fraunhofer ISI.

Concentration of production at the level of countries

The last term in Equation 4 above simultaneously characterizes both the concentration of production at the country level and the governance in / environmental performance of those countries. This is done by modifying the Herfindahl-Hirschmann-Index in two ways:

1. by performing the calculations using production at a country level instead of at a company level
2. by multiplying the share of production of each country by its score in the World Governance Index, published regularly by the World Bank.

This index includes six categories: voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption. The simple average of these six categories is used in the calculations. Note that the WGI have a range of -2.5 to +2.5, where lower scores correspond to poorer governance. However, poor governance is seen as a risk factor such that the range of the WGI has to be inverted such that higher values correspond to poorer governance (higher risk). The calculation of this index then takes the form in Equation 5.

Equation 5: Calculation of the Herfindahl-Hirschmann-Index for country concentration

$$HHI_{WGI} = \sum_{c} (S_c^2 WGI_c)$$

Here WGI_c is the rescaled[a] score in the World Governance Indicators of country c and S_c is the % share of country c in world production of the raw material considered. This provides the basis for calculating the supply risk due to poor governance.

The risk of a supply restriction due to environmental concerns, e.g. the closing of mines due to the adoption of stricter environmental regulation, is also considered separately. The AHWG argued that this risk is higher in countries with poor environmental management, which may enter a process of modernization of their environmental regulations. Moreover, countries with strong environmental legislation are seen to be better suited to cope with the risks associated with mining and processing of raw materials. To assess the quality and effectiveness of environmental regulation, the Environmental Performance Index was selected. The calculation of environmental risk is fully analogous to that described above based on the World Bank Governance Index, but substituting WGI_c by the Environmental Performance Index.[b]

---

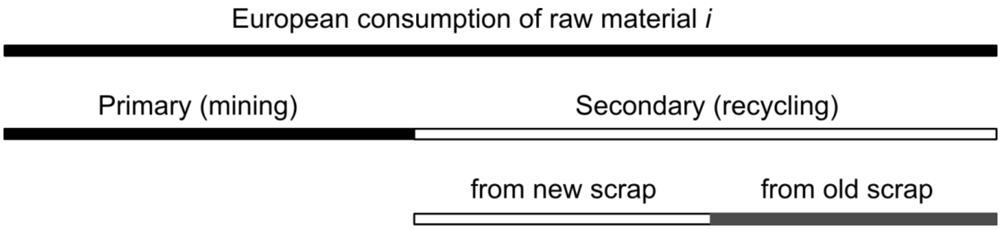
[a] The values are also rescaled linearly such that they fit in the range 0-10 instead of -2.5 to +2.5 prior to applying Equation 3.

[b] The EPI can be obtained from http://epi.yale.edu/. Note that the values of the EPI must also be rescaled to fit the logic shown in Figure 49: a) by inverting the order of the values (higher scores for lower environmental standards), and b) by rescaling linearly to the range 0-10 such that the scores are more directly comparable to those of the Governance Indicators.

The role of recycling

The risks assigned to the producing countries do not apply to material recycled within the EU[a]. Assuming this production to be riskless, the factor $(1-\rho)$ serves to scale the risk of primary production to account for recycling. At the extreme, if the recycling rate is zero, the risks of primary production apply to the entire supply of the raw material. The higher the fractional recycling rate, the smaller the term $(1-\rho)$ becomes, reflecting that the risks associated with primary production do not affect the entire supply of the raw material considered. This relation is presented schematically in Figure 50. Notice that this assessment only considers recycling from old scrap in the calculation of supply risk.

Figure 50: Schematic representation (not to scale) of recycling as included in the EU criticality exercise: only recycling from old scrap is considered in the calculation of supply risk.



Accounting for substitutability of raw materials

Raw materials are used in products to provide a function. Thus, it is possible to substitute one raw material for another provided the intended function is adequately performed by the substitute. This potential for substitution is captured by the term σ_s, which is the estimated substitution potential for a raw material in a particular end-use sector s. Thus, a weighted sum may be constructed as to characterize the overall substitutability of a raw material, Equation 6.

Equation 6: Calculation of overall substitutability of a raw material

$$\sigma_i = \sum_s A_s \sigma_s$$

Where A_s is (as before) the share of net consumption of raw material i in end-use sector s, and σ_s the corresponding substitutability index. This index was estimated by expert judgement and subject to review by experts internal and external to the Working Group. A similar procedure is to be followed in this reassessment. Possible values for substitutability are:

0.0	Easily and completely substitutable at no additional cost
0.3	Substitutable at low cost
0.7	Substitutable at high cost and/or loss of performance
1.0	Not substitutable.

In the context of the supply risk equation, this means that if a raw material is not substitutable, the risks of production (after recycling is accounted for) fully apply to the value of the raw material, as expressed by its economic importance. In contrast, if a raw material was immediately and fully substitutable at no additional costs, the risk associated with primary production would not apply to the economy because the same function could be performed by a different raw material, leading to no supply risk. Notice that this approach does not explicitly include the supply risks associated with the substitute. These are included in the estimates of σ_s on the basis of expert judgement.

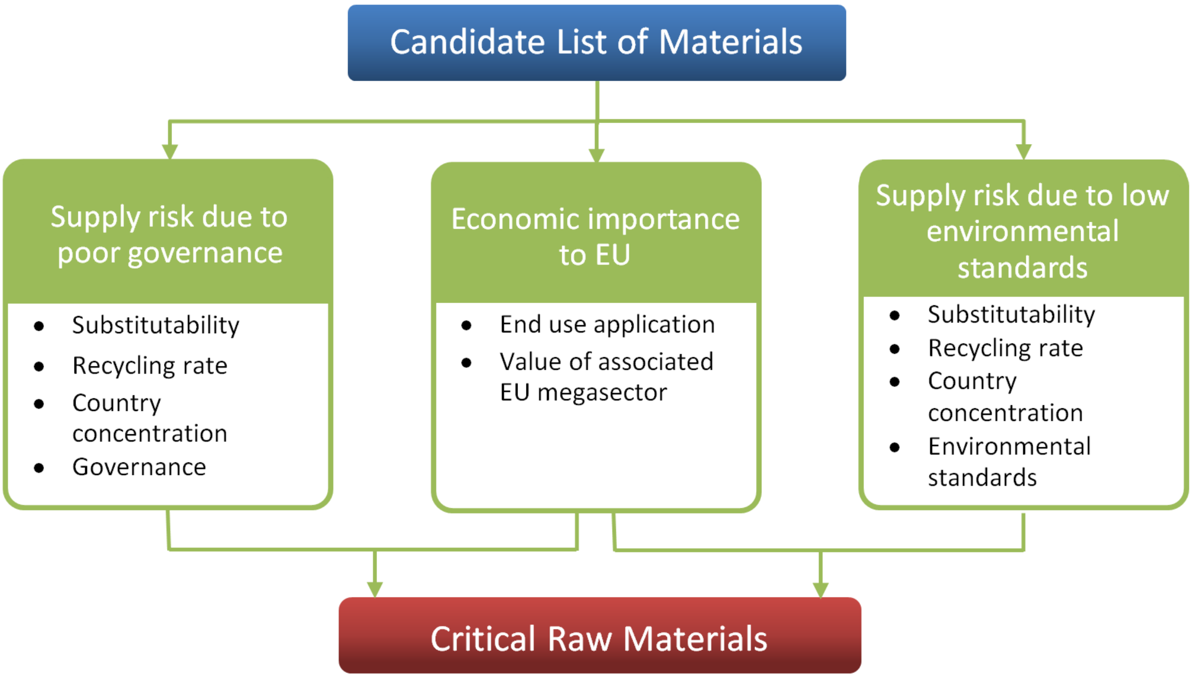
---

[a] Global recycling rates are used because EU specific rates are generally not available.

Summary

The methodology uses the compound indicators “Economic importance” and at least one of the two measures of the compound “Supply risk” indicator to generate a relative ranking of the raw materials in the list of candidates. Thresholds are introduced for each of these dimensions to differentiate between raw materials considered critical and non-critical. The factors considered and process are summarised in the schematic in Figure 51.

Figure 51: Schematic of EU criticality methodology



Annex C – Statistical Information for Criticality Assessment

This Annex contains the following information, used in the criticality assessment; Megasector assignments and values, WGI (scaled), EPI (scaled), End use data sources and locality, and Production data sources.

Megasector values and assignments

Megasector	**2010**		**2006**		**Change (2006 to 2010)**		
	VA (€M)	**%**	**VA (€M)**	**%**	**VA (€M)**	**% VA**	**%**
Construction Material	104,441	5.72%	98,452	5.75%	5,989	6%	-0.03%
Metals	164,623	9.01%	189,013	11.04%	-24,390	-13%	-2.03%
Mechanical Equipment	182,406	9.98%	181,548	10.61%	858	0%	-0.63%
Electronics & ICT	104,855	5.74%	123,098	7.19%	-18,243	-15%	-1.45%
Electrical Equipment & Dom. Appliances	88,139	4.82%	83,746	4.89%	4,393	5%	-0.07%
Road Transport	147,442	8.07%	156,252	9.13%	-8,810	-6%	-1.06%
Aircraft, Shipbuilding, Trains	51,222	2.80%	48,242	2.82%	2,980	6%	-0.02%
Other Final Consumer Goods	63,280	3.46%	69,479	4.06%	-6,199	-9%	-0.60%
Food	164,978	9.03%	154,417	9.02%	10,561	7%	0.01%
Beverages	37,000	2.02%	34,000	1.99%	3,000	9%	0.03%
Paper	41,276	2.26%	41,065	2.40%	211	1%	-0.14%
Wood	46,493	2.54%	37,148	2.17%	9,345	25%	0.37%
Pharmaceuticals	85,872	4.70%	70,500	4.12%	15,372	22%	0.58%
Chemicals	108,804	5.95%	116,377	6.80%	-7,573	-7%	-0.85%
Rubber, Plastic & Glass	98,135	5.37%	100,382	5.86%	-2,247	-2%	-0.49%
Refining	29,239	1.60%	33,463	1.95%	-4,224	-13%	-0.35%
Total	**1,518,205**	**83.08%**	**1,532,493**	**89.80%**	**-14,288**	**-1%**	**-6.72%**
Non-manufacturing megasectors included							
Oil & Gas Extraction	50,010	2.74%	59,223	3.46%	-9,213	-0.16	-0.72%
Mining of Metal Ores	4,483	0.25%	4,993	0.29%	-510	-0.1	-0.04%
Total Manufacturing VA in Europe (Adjusted for 2010 Due to Change in NACE Classification)	1,827,427	100%	1,711,786	100%			
<u>Not Included</u>							
Textiles & Clothes	53,207	3.00%	64,430	3.76%			
Publishing & Printing	82,714	4.67%	96,331	5.63%			
Tobacco	6,949	0.39%	8,250	0.48%			
Sum used in analysis	**1,715,567**	**94.0%**	**1,701,504**	**99.7%**			

Due to a change in Eurostat's NACE classification to Rev2 from Rev1.1, it has been necessary to replicate the mega sectors constructed in 2010 using Rev1.1 NACE classes using NACE Rev2 classes. This allows the use of the most recent GVA for 2010 . This change in NACE classification can be considered more than a simple change of labelling of the NACE categories. Several categories have been split up to gain precision while others where combined. Eurostat characterizes the change in classification as follows:

“In order to have an idea of the impact of changes on official statistics due to the implementation of NACE Rev. 2, it is useful to distinguish the following types of correspondences between NACE Rev. 1.1 and NACE Rev. 2:

- 1-to-1 correspondences: 195 classes in NACE Rev. 1.1 correspond exactly to one class in NACE Rev. 2 and *vice versa*
- n-to-1 correspondences: 86 cases, where two or more classes in NACE Rev 1.1 correspond to one class in NACE Rev. 2
- 1-to-m correspondences: 18 cases, where one NACE Rev. 1.1 class is split into two or more classes in NACE Rev 2
- n-to-m correspondences: 215 cases, where two or more classes in NACE Rev. 1.1 correspond to two or more classes in NACE Rev. 2.”

As a result there are now more NACE groups and classes than previously, with some not included in manufacturing. Therefore to calculate the percentage shares of each megasector overall manufacturing GVA it had been necessary to determine an adjusted “Total Manufacturing VA in Europe”. However, this is only relevant to the several NACE classes that have been moved from Manufacturing in 2010 compared with previously, for instance Publishing and Printing. The reassignments used in this study are outlined below, this does not represent a one-to-one mapping.

	NACE Rev 1.1	**NACE Rev 2**
Construction Material	DI262 - Manufacture of non-refractory ceramic goods other than for construction purposes; manufacture of refractory ceramic products	234 - Manufacture of other porcelain and ceramic products
	DI263 - Manufacture of ceramic tiles and flags	232 - Manufacture of refractory ceramic products
	DI264 - Manufacture of bricks, tiles and construction products, in baked clay	233 - Manufacture of clay building materials
	DI265 - Manufacture of cement, lime and plaster	235 - Manufacture of cement, lime and plaster
	DI266 - Manufacture of articles of concrete, plaster and cement	236 - Manufacture of articles of concrete, plaster and cement
	DI267 - Cutting, shaping and finishing of ornamental and building stone	237 - Cutting, shaping and finishing of ornamental and building stone
	DJ281 - Manufacture of structural metal products	251 - Manufacture of structural metal products
		2433 - Cold forming or folding
		4332 - Joinery installation

	NACE Rev 1.1	**NACE Rev 2**
Metals	DJ271 - Manufacture of basic iron and steel and of ferro-alloys	241 - Manufacture of basic iron and steel and of ferro-alloys
	DJ272 - Manufacture of tubes	242 - Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
	DJ273 - Other first processing of iron and steel	243 - Manufacture of other products of first processing of steel
	DJ274 - Manufacture of basic precious and non-ferrous metals	245 - Casting of metals
	DJ275 - Casting of metals	253 - Manufacture of steam generators, except central heating hot water boilers
	DJ282 - Manufacture of tanks, reservoirs and containers of metal; manufacture of central heating radiators and boilers	255 - Forging, pressing, stamping and roll-forming of metal; powder metallurgy
	DJ283 - Manufacture of steam generators, except central heating hot water boilers	256 - Treatment and coating of metals; machining
	DJ284 - Forging, pressing, stamping and roll forming of metal; powder metallurgy	259 - Manufacture of other fabricated metal products
	DJ285 - Treatment and coating of metals; general mechanical engineering	383 - Materials recovery

	DJ287 - Manufacture of other fabricated metal products	2441 - Precious metals production
		2442 - Aluminium production
		2443 - Lead, zinc and tin production
		2444 - Copper production
		2445 - Other non-ferrous metal production
		2521 - Manufacture of central heating radiators and boilers
		2529 - Manufacture of other tanks, reservoirs and containers of metal
		3299 - Other manufacturing n.e.c.
		3311 - Repair of fabricated metal products
	NACE Rev 1.1	**NACE Rev 2**
Mechanical Equipment	DK291 - Manufacture of machinery for the production and use of mechanical power, except aircraft, vehicle and cycle engines	281 - Manufacture of general-purpose machinery
	DK292 - Manufacture of other general purpose machinery	289 - Manufacture of other special-purpose machinery
	DK293 - Manufacture of agricultural and forestry machinery	283 - Manufacture of agricultural and forestry machinery
	DK294 - Manufacture of machine-tools	2821 - Manufacture of ovens, furnaces and furnace burners
	DK295 - Manufacture of other special purpose machinery	2822 - Manufacture of lifting and handling equipment
		2824 - Manufacture of power-driven hand tools
		2825 - Manufacture of non-domestic cooling and ventilation equipment
		2829 - Manufacture of other general-purpose machinery n.e.c.
		2841 - Manufacture of metal forming machinery
		2849 - Manufacture of other machine tools
		3312 - Repair of machinery
		9522 - Repair of household appliances and home and garden equipment
	NACE Rev 1.1	**NACE Rev 2**
Electronics & ICT	DL300 - Manufacture of office machinery and computers	261 - Manufacture of electronic components and boards
	DL321 - Manufacture of electronic valves and tubes and other electronic components	262 - Manufacture of computers and peripheral equipment
	DL322 - Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy	263 - Manufacture of communication equipment
	DL323 - Manufacture of television and radio receivers, sound or video recording or reproducing apparatus and associated goods	264 - Manufacture of consumer electronics
	DL331 - Manufacture of medical and surgical equipment and orthopaedic appliances	265 - Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks
	DL332 - Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment	266 - Manufacture of irradiation, electro-medical and electrotherapeutic equipment
	DL333 - Manufacture of industrial process control equipment	267 - Manufacture of optical instruments and photographic equipment
	DL334 - Manufacture of optical instruments and photographic equipment	325 - Manufacture of medical and dental instruments and supplies
	DL335 - Manufacture of watches and clocks	332 - Installation of industrial machinery and equipment
		2823 - Manufacture of office machinery and equipment (except computers and peripheral equipment)
		3313 - Repair of electronic and optical equipment
		9512 - Repair of communication equipment

	NACE Rev 1.1	NACE Rev 2

Electrical Equipment + Domestic Appliances	DL311 - Manufacture of electric motors, generators and transformers	271 - Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus
	DL312 - Manufacture of electricity distribution and control apparatus	272 - Manufacture of batteries and accumulators
	DL313 - Manufacture of insulated wire and cable	273 - Manufacture of wiring and wiring devices
	DL314 - Manufacture of accumulators, primary cells and primary batteries	274 - Manufacture of electric lighting equipment
	DL315 - Manufacture of lighting equipment and electric lamps	275 - Manufacture of domestic appliances
	DL316 - Manufacture of electrical equipment n.e.c.	279 - Manufacture of other electrical equipment
	DK297 - Manufacture of domestic appliances n.e.c.	3314 - Repair of electrical equipment

	NACE Rev 1.1	**NACE Rev 2**
Road Transport	DM341 - Manufacture of motor vehicles	291 - Manufacture of motor vehicles
	DM342 - Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers	292 - Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers
	DM343 - Manufacture of parts and accessories for motor vehicles and their engines	293 - Manufacture of parts and accessories for motor vehicles
	DM354 - Manufacture of motorcycles and bicycles	309 - Manufacture of transport equipment n.e.c.
		3317 - Repair and maintenance of other transport equipment

	NACE Rev 1.1	**NACE Rev 2**
Aircraft, Shipbuilding, Trains	DM351 - Building and repairing of ships and boats	301 - Building of ships and boats
	DM352 - Manufacture of railway and tramway locomotives and rolling stock	302 - Manufacture of railway locomotives and rolling stock
	DM353 - Manufacture of aircraft and spacecraft	303 - Manufacture of air and spacecraft and related machinery
		3315 - Repair and maintenance of ships and boats
		3316 - Repair and maintenance of aircraft and spacecraft

	NACE Rev 1.1	**NACE Rev 2**
Other Final Consumer Goods	DN361 - Manufacture of furniture	310 - Manufacture of furniture
	DN362 - Manufacture of jewellery and related articles	321 - Manufacture of jewellery, bijouterie and related articles
	DN363 - Manufacture of musical instruments	322 - Manufacture of musical instruments
	DN364 - Manufacture of sports goods	323 - Manufacture of sports goods
	DN365 - Manufacture of games and toys	324 - Manufacture of games and toys
	DN366 - Miscellaneous manufacturing n.e.c.	257 - Manufacture of cutlery, tools and general hardware
	DJ286 - Manufacture of cutlery, tools and general hardware	264 - Manufacture of consumer electronics
		3291 - Manufacture of brooms and brushes
		3319 - Repair of other equipment
		9524 - Repair of furniture and home furnishings
		9529 - Repair of other personal and household goods

	NACE Rev 1.1	NACE Rev 2
Food	DA151 - Production, processing, preserving of meat and meat products	101 - Processing and preserving of meat and production of meat products
	DA152 - Processing and preserving of fish and fish products	102 - Processing and preserving of fish, crustaceans and molluscs
	DA153 - Processing and preserving of fruit and vegetables	103 - Processing and preserving of fruit and vegetables
	DA154 - Manufacture of vegetable and animal oils and fats	104 - Manufacture of vegetable and animal oils and fats
	DA155 - Manufacture of dairy products	105 - Manufacture of dairy products
	DA156 - Manufacture of grain mill products, starches and starch products	106 - Manufacture of grain mill products, starches and starch products
	DA157 - Manufacture of prepared animal feeds	107 - Manufacture of bakery and farinaceous products
	DA158 - Manufacture of other food products	108 - Manufacture of other food products
		109 - Manufacture of prepared animal feeds

	NACE Rev 1.1	NACE Rev 2
Beverages	DA159 - Manufacture of beverages	110 - Manufacture of beverages

	NACE Rev 1.1	NACE Rev 2
Tobacco	DA160 - Manufacture of tobacco products	120 - Manufacture of tobacco products

	NACE Rev 1.1	NACE Rev 2
Textiles & Clothes	DB171 - Preparation and spinning of textile fibres	131 - Preparation and spinning of textile fibres
	DB172 - Textile weaving	132 - Weaving of textiles
	DB173 - Finishing of textiles	133 - Finishing of textiles
	DB174 - Manufacture of made-up textile articles, except apparel	139 - Manufacture of other textiles
	DB175 - Manufacture of other textiles	141 - Manufacture of wearing apparel, except fur apparel
	DB176 - Manufacture of knitted and crocheted fabrics	142 - Manufacture of articles of fur
	DB177 - Manufacture of knitted and crocheted articles	143 - Manufacture of knitted and crocheted apparel
	DB182 - Manufacture of other wearing apparel and accessories	151 - Tanning and dressing of leather; manufacture of luggage, handbags, saddlery and harness; dressing and dyeing of fur
	DB183 - Dressing and dyeing of fur; manufacture of articles of fur	152 - Manufacture of footwear
	DC191 - Tanning and dressing of leather	
	DC192 - Manufacture of luggage, handbags and the like, saddler	
	DC193 - Manufacture of footwear	
	DB181 - Manufacture of leather clothes	

	NACE Rev 1.1	NACE Rev 2
Wood	DD201 - Sawmilling and planing of wood; impregnation of wood	161 - Sawmilling and planing of wood
	DD202 - Manufacture of veneer sheets; manufacture of plywood, laminboard, particle board, fibre board and other panels and boards	162 - Manufacture of products of wood, cork, straw and plaiting materials
	DD203 - Manufacture of builders”carpentry and joinery	
	DD204 - Manufacture of wooden containers	4391 - Roofing activities
	DD205 - Manufacture of other products of wood; manufacture of articles of cork, straw and plaiting materials	

	NACE Rev 1.1	NACE Rev 2

Paper	DE211 - Manufacture of pulp, paper and paperboard	171 - Manufacture of pulp, paper and paperboard
	DE212 - Manufacture of articles of paper and paperboard	172 - Manufacture of articles of paper and paperboard
	NACE Rev 1.1	**NACE Rev 2**
Publishing Printing	DE221 - Publishing	581 - Publishing of books, periodicals and other publishing activities
	DE222 - Printing and service activities related to printing	181 - Printing and service activities related to printing
	DE223 - Reproduction of recorded media	182 - Reproduction of recorded media
		592 - Sound recording and music publishing activities
	NACE Rev 1.1	**NACE Rev 2**
Pharmaceuticals	DG244 - Manufacture of pharmaceuticals, medicinal chemicals and botanical products	211 - Manufacture of basic pharmaceutical products
		212 - Manufacture of pharmaceutical preparations
	NACE Rev 1.1	**NACE Rev 2**
Chemicals	DG241 - Manufacture of basic chemicals	201 - Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
	DG242 - Manufacture of pesticides and other agro-chemical products	202 - Manufacture of pesticides and other agrochemical products
	DG243 - Manufacture of paints, varnishes and similar coatings, printing ink and mastics	203 - Manufacture of paints, varnishes and similar coatings, printing ink and mastics
	DG245 - Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	204 - Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations
	DG246 - Manufacture of other chemical products	205 - Manufacture of other chemical products
	DG247 - Manufacture of man-made fibres	206 - Manufacture of man-made fibres
		268 - Manufacture of magnetic and optical media
	NACE Rev 1.1	**NACE Rev 2**
Rubber, Plastic & Glass	DH251 - Manufacture of rubber products	221 - Manufacture of rubber products
	DH252 - Manufacture of plastic products	222 - Manufacture of plastics products
	DI261 - Manufacture of glass and glass products	231 - Manufacture of glass and glass products
	DI268 - Manufacture of other non-metallic mineral products	239 - Manufacture of abrasive products and non-metallic mineral products n.e.c.
	NACE Rev 1.1	**NACE Rev 2**
Refining	DF231 - Manufacture of coke oven products	191 - Manufacture of coke oven products
	DF232 - Manufacture of refined petroleum products	192 - Manufacture of refined petroleum products
	DF233 - Processing of nuclear fuel	2446 - Processing of nuclear fuel
		3812 - Collection of hazardous waste
		3822 - Treatment & disposal of hazardous waste

WGI and EPI values (Scaled)

Country	WGI	WGI (scaled)	EPI	EPI (scaled)
Afghanistan	-1.75	8.50	20.64	7.94
Albania	-0.20	5.40	65.85	3.42
Algeria	-0.93	6.86	48.56	5.14
Argentina	-0.22	5.43	56.48	4.35
Armenia	-0.27	5.55	47.48	5.25
Australia	1.63	1.74	56.61	4.34
Austria	1.49	2.03	68.92	3.11
Azerbaijan	-0.85	6.69	43.11	5.69
Bahrain	0.04	4.93	41.39	5.86
Bangladesh	-0.87	6.73	42.55	5.74
Belarus	-1.01	7.01	53.88	4.61
Belgium	1.37	2.26	63.02	3.70
Bhutan	0.12	4.77	53.73	4.63
Bolivia, Plurinational State of	-0.54	6.07	54.57	4.54
Bosnia and Herzegovina	-0.42	5.83	36.76	6.32
Botswana	0.69	3.62	53.74	4.63
Brazil	0.13	4.73	60.90	3.91
Bulgaria	0.18	4.64	56.28	4.37
Burkina Faso	-0.38	5.76	39.17	6.08
Burundi	-1.19	7.38	40.69	5.93
Cambodia	-0.78	6.56	55.29	4.47
Cameroon	-0.89	6.78	42.97	5.70
Canada	1.62	1.76	58.41	4.16
Chile	1.21	2.58	55.34	4.47
China	-0.59	6.18	42.24	5.78
Colombia	-0.23	5.46	62.33	3.77
Congo, the Democratic Republic of the	-1.64	8.28	47.49	5.25
Costa Rica	0.58	3.84	69.03	3.10
Côte d'Ivoire	-1.16	7.32	53.55	4.65
Croatia	0.38	4.24	64.16	3.58
Cuba	-0.53	6.06	56.48	4.35
Cyprus	1.06	2.87	57.15	4.28
Czech Republic	0.95	3.10	64.79	3.52
Denmark	1.86	1.28	63.61	3.64
Dominican Republic	-0.36	5.73	52.44	4.76
Ecuador	-0.76	6.52	60.55	3.94
Egypt	-0.74	6.48	55.18	4.48
Eritrea	-1.40	7.81	38.39	6.16
Estonia	1.06	2.88	56.09	4.39
Ethiopia	-0.96	6.92	52.71	4.73
Fiji	-0.60	6.19	54.30	4.57
Finland	1.85	1.31	64.44	3.56
France	1.21	2.57	69.00	3.10
French Guiana	1.00	2.99	66.45	3.35
Gabon	-0.55	6.10	57.91	4.21
Georgia	0.02	4.97	56.84	4.32
Germany	1.42	2.16	66.91	3.31
Ghana	0.14	4.72	47.50	5.25
Greece	0.36	4.28	60.04	4.00
Greenland	1.41	2.18	76.79	2.32
Guatemala	-0.57	6.15	51.88	4.81
Guinea	-1.19	7.38	37.30	6.27
Guyana	-0.38	5.75	54.32	4.57
Honduras	-0.55	6.11	52.54	4.75
Hungary	0.74	3.51	57.12	4.29

Country	WGI	WGI (scaled)	EPI	EPI (scaled)
Iceland	1.48	2.04	66.28	3.37
India	-0.30	5.60	36.23	6.38
Indonesia	-0.47	5.93	52.29	4.77
Iran, Islamic Republic of	-1.16	7.32	42.73	5.73
Iraq	-1.34	7.69	25.32	7.47
Ireland	1.44	2.11	58.69	4.13
Israel	0.59	3.81	54.64	4.54
Italy	0.52	3.96	68.90	3.11
Jamaica	0.01	4.98	54.36	4.56
Japan	1.17	2.66	63.36	3.66
Jordan	-0.13	5.25	42.16	5.78
Kazakhstan	-0.59	6.18	32.94	6.71
Kenya	-0.69	6.39	49.28	5.07
Korea, Democratic People's Republic of[†]	-1.61	8.22		
Korea, Republic of	0.76	3.47	57.20	4.28
Kyrgyzstan	-0.83	6.67	46.33	5.37
Lao People's Democratic Republic	-0.91	6.82	53.76	4.62
Latvia	0.61	3.77	70.37	2.96
Liberia	-0.73	6.46	35.25	6.47
Macedonia, the former Yugoslav Republic of	-0.08	5.16	46.96	5.30
Madagascar	-0.71	6.42	43.49	5.65
Malawi	-0.34	5.68	40.35	5.96
Malaysia	0.32	4.37	62.51	3.75
Mali	-0.49	5.97	30.04	7.00
Mauritania	-0.88	6.76	24.05	7.60
Mexico	-0.13	5.26	49.11	5.09
Mongolia	-0.22	5.44	45.37	5.46
Montenegro	0.10	4.79	60.70	3.93
Morocco	-0.33	5.65	45.76	5.42
Mozambique	-0.30	5.60	47.82	5.22
Myanmar	-1.65	8.30	52.72	4.73
Namibia	0.30	4.41	50.68	4.93
Nauru	0.13	4.74	37.50	6.25
Nepal	-0.89	6.78	57.97	4.20
Netherlands	1.71	1.58	65.65	3.43
New Caledonia	-0.17	5.35	64.53	3.55
New Zealand	1.83	1.34	66.05	3.40
Nicaragua	-0.61	6.22	59.23	4.08
Niger	-0.58	6.16	32.60	6.74
Nigeria	-1.15	7.30	40.14	5.99
Norway	1.70	1.59	69.92	3.01
Oman	0.19	4.62	44.00	5.60
Pakistan	-1.14	7.29	39.56	6.04
Panama	0.08	4.84	57.94	4.21
Papua New Guinea	-0.69	6.37	52.16	4.78
Paraguay	-0.60	6.20	52.40	4.76
Peru	-0.18	5.37	50.29	4.97
Philippines	-0.49	5.99	57.40	4.26
Poland	0.83	3.33	63.47	3.65
Portugal	0.93	3.15	57.64	4.24
Qatar	0.55	3.89	46.59	5.34
Romania	0.15	4.71	48.34	5.17
Russian Federation	-0.74	6.48	45.43	5.46
Rwanda	-0.21	5.42	38.45	6.16
Saudi Arabia	-0.47	5.93	49.97	5.00
Senegal	-0.39	5.78	46.73	5.33
Serbia	-0.12	5.24	46.14	5.39

Country	WGI	WGI (scaled)	EPI	EPI (scaled)
Sierra Leone	-0.65	6.30	36.69	6.33
Slovakia	0.79	3.42	66.62	3.34
Slovenia	0.92	3.17	62.25	3.78
Solomon Islands	-0.43	5.86	51.50	4.85
South Africa	0.25	4.49	34.55	6.54
Spain	0.94	3.13	60.31	3.97
Sri Lanka	-0.29	5.58	55.72	4.43
Sudan	-1.60	8.19	46.00	5.40
Suriname	-0.10	5.21	65.91	3.41
Sweden	1.80	1.39	68.82	3.12
Syrian Arab Republic	-1.10	7.21	42.75	5.72
Taiwan, Province of China	1.01	2.98	62.23	3.78
Tajikistan	-1.10	7.20	38.78	6.12
Tanzania, United Republic of	-0.36	5.71	54.26	4.57
Thailand	-0.29	5.58	59.98	4.00
Togo	-0.89	6.78	48.66	5.13
Tunisia	-0.18	5.36	46.66	5.33
Turkey	-0.01	5.03	44.80	5.52
Turkmenistan	-1.41	7.81	31.75	6.82
Uganda	-0.60	6.19	38.29	6.17
Ukraine	-0.58	6.16	46.31	5.37
United Arab Emirates	0.48	4.04	50.91	4.91
United Kingdom	1.34	2.33	68.82	3.12
United States	1.23	2.53	56.59	4.34
Uruguay	0.84	3.32	57.06	4.29
Uzbekistan	-1.29	7.57	32.24	6.78
Venezuela, Bolivarian Republic of	-1.28	7.55	55.62	4.44
Viet Nam	-0.55	6.10	50.64	4.94
Zambia	-0.30	5.60	55.56	4.44
Zimbabwe	-1.48	7.95	52.76	4.72

† The contribution from People's Republic of Korea was ignored for EPI assessment as no value is available. This has no impact on the overall assessment as the production of materials is small.

End use data sources and locality

Material	Location	Year	Source
Aluminium	Europe	2010	European Aluminium Association
Antimony	Europe	2011	Roskill
Barytes	US	2012	U.S. Geological Survey
Bauxite	US	2012	U.S. Geological Survey
Bentonite	Europe	2011	IMA-Europe
Beryllium	Europe	2012	BeST2013
Borate	Europe	2012	IMA-Europe
Chromium	US	2012	U.S. Geological Survey
Clays	Europe	2010	CRM2010
Cobalt	Worldwide	2011	Cobalt Facts, CDI 2012
Coking coal	Worldwide	2007	intertechpira
Copper	Europe	2011	ICA
Diatomite	US	2012	U.S. Geological Survey
Feldspar	US	2012	U.S. Geological Survey
Fluorspar	Worldwide	2010	CRM2010
Gallium	Worldwide	2010	Indium Corp
Germanium	Worldwide	2012	U.S. Geological Survey
Gold	Worldwide	2012	World Gold Council
Gypsum	US	2012	U.S. Geological Survey
Hafnium	Worldwide	2011	Lipmann, Walton & Co
Heavy Rare Earth Elements	Worldwide	2012	Roskill & USGS
Indium	Worldwide	2011	Indium Corp
Iron	Europe	2010	CRM 2010
Light Rare Earth Elements	Worldwide	2012	Roskill & USGS
Limestone	Europe	2007	CRM2010
Lithium	Worldwide	2011	Roskill 2012 in mineral info 2012
Magnesite	Europe	2010	CRM2010
Magnesium	Europe	2012	Roskill
Manganese	Europe	2012	Euro Alliages 2013
Molybdenum	Worldwide	2010	SMR GmbH, Steel & Metals Market Research 2011
Natural Graphite	Worldwide	2012	Roskill 2013 in 37th ECGA General Assembly
Natural rubber	Europe	2012	ETRMA
Nickel	Europe	2010	Nickel Institute
Niobium	Worldwide	2010	Heraeus 2010 (taken from CBMM)
Perlite	US	2011	U.S. Geological Survey
Phosphate Rock	US	2012	U.S. Geological Survey
Platinum Group Metals	Worldwide	2012	Johnson Matthey Interim Review 2012
Potash	Worldwide	2011	U.S. Geological Survey
Pulpwood	Europe	2012	Confederation of European Paper Industry
Rhenium	Worldwide	2011	Lipmann, Walton & Co
Sawn Softwood	Europe	2011	European Organisation of the Sawmill Industry
Scandium	Worldwide	2011	INSG
Selenium	Worldwide	2011	U.S. Geological Survey
Silica sand	Europe	2010	CRM2010
Silicon	Europe	2010	Euroalliages
Silver	Worldwide	2011	Silver Institute
Talc	Europe	---	IMA-Europe
Tantalum	Worldwide	2011	Roskill 2013 in Minor Metals Conf
Tellurium	Worldwide	2010	STDA
Tin	Worldwide	2011	ITRI
Titanium	US	2012	U.S. Geological Survey
Tungsten	Worldwide	2010	CRM2010
Vanadium	Worldwide	2012	Roskill 2013 in Titantium Europe Conf
Zinc	Worldwide	---	ILZSG

Production data sources

Material	Year	Source
Aluminium	2010	World Mining Data
Antimony	2011	World Mining Data
Barytes	2010	World Mining Data
Bauxite	2011	Raw Materials Data
Bentonite	2010	World Mining Data
Beryllium	2011	U.S. Geological Survey
Borate	2010	World Mining Data
Chromium	2010	World Mining Data
Clays	2010	World Mining Data
Cobalt	2010	U.S. Geological Survey
Coking coal	2010	World Mining Data
Copper	2010	U.S. Geological Survey
Diatomite	2010	World Mining Data
Feldspar	2010	U.S. Geological Survey
Fluorspar	2010	World Mining Data
Gallium	2011	U.S. Geological Survey
Germanium	2011	Germanium Corporation
Gold	2011	Raw Materials Data
Gypsum	2010	World Mining Data and U.S. Geological Survey
Hafnium	2012	Lipmann, Walton & Co
Heavy Rare Earth Elements	2012	Roskill, IMCOA, U.S. Geological Survey
Indium	2012	U.S. Geological Survey
Iron	2010	World Mining Data
Light Rare Earth Elements	2012	World Mining Data and U.S. Geological Survey
Limestone	2012	Roskill
Lithium	2011	World Mining Data
Magnesite	2010	World Mining Data
Magnesium	2011	U.S. Geological Survey
Manganese	2010	World Mining Data
Molybdenum	2010	World Mining Data
Natural Graphite	2012	U.S. Geological Survey
Natural rubber	2012	International Rubber Study Group
Nickel	2011	Raw Materials Data
Niobium	2010	U.S. Geological Survey
Perlite	2011	U.S. Geological Survey
Phosphate Rock	2010	World Mining Data
Platinum Group Metals	2012	Johnson Matthey and U.S. Geological Survey
Potash	2012	U.S. Geological Survey
Pulpwood	2011	FAOstat
Rhenium	2011	Lipmann, Walton & Co
Sawn Softwood	2011	European Organisation of the Sawmill Industry
Scandium	2011	INSG
Selenium	2011	ILZSG
Silica sand	2012	U.S. Geological Survey
Silicon	2011	BGS
Silver	2012	Raw Materials Data
Talc	2010	World Mining Data
Tantalum	2011	Raw Materials Data
Tellurium	2011	ILZSG
Tin	2012	World Bureau of Metal Statistics, ITRI, Direccao Geral de Energia e Geologia (Portugal), compiled by BGR
Titanium	2010	World Mining Data
Tungsten	2010	World Mining Data
Vanadium	2010	World Mining Data
Zinc	2010	U.S. Geological Survey

NB: Data from these sources was used in the analysis. Data presented the material profiles differs in some cases due to data confidentiality

Annex D – Worked Example of Assessment Calculation

The quantitative methodology for assessing both supply risk and economic importance is described in Annex B. For the purpose of illustration, step-by-step calculations for niobium and lithium are shown here.

End use data and economic importance
This analysis starts with the data on end uses of niobium and the assessment of its substitutability in the different applications as follows:

Niobium – End Uses

Use	Share	Substitutability Index	Contribution to Substitutability (Share x Subst Index)
Steel: Automotive	28%	0.7	0.2
Steel: Chemical industry	3%	0.7	0.02
Steel: Pipeline	24%	0.7	0.17
Steel: Structural	31%	0.7	0.22
Superalloys	8%	0.7	0.06
Others	6%	0.5	0.03
			0.69

Lithium – End Uses

Use	Share	Substitutability Index	Contribution to Substitutability (Share x Subst Index)
Ceramics and glass	30%	1.0	0.30
Other	22%	0.5	0.11
Batteries	22%	1.0	0.22
Lubricating grease	11%	0.7	0.08
Gas and air treatment	4%	0.3	0.01
Continuous casting	4%	0.7	0.03
Synthetic rubbers and plastics	3%	0.7	0.02
Pharmaceuticals	2%	0.3	0.01
Aluminium smelting	2%	0.3	0.01
			0.78

The sum of “contribution to substitutability” is the weighted substitutability score used later in the estimation of supply risk. The end uses now need to be matched to the pertinent megasectors (and their value, see Annex C) to calculate the economic importance:

Niobium - Substitutability

Use	Share	Megasector	Megasector GVA	Contribution to Econ. Import. (Share x Megasector GVA)
Steel: Automotive	28%	Transport-Road	147.44	41.28
Steel: Chemical industry	3%	MechEquip	182.41	5.47
Steel: Pipeline	24%	Oil	50.01	12.00
Steel: Structural	31%	Construction	104.44	32.38
Superalloys	8%	Metals	164.62	13.17
Others	6%	Other	63.28	3.80
				108.10

Lithium – Substitutability

Use	Share	Megasector	Megasector GVA	Contribution to Econ. Import. (Share x Megasector GVA)
Ceramics and glass	30%	Plastic	98.13	29.44
Other	22%	Other	63.28	13.92
Batteries	22%	Electronics	104.86	23.07
Lubricating grease	11%	Chemicals	108.80	11.97
Gas and air treatment	4%	MechEquip	182.41	7.30
Continuous casting	4%	Metals	164.62	6.58
Synthetic rubbers and plastics	3%	Plastic	98.13	2.94
Pharmaceuticals	2%	Pharma	85.87	1.72
Aluminium smelting	2%	Metals	164.62	3.29
				100.23

The sum of “contribution to economic importance” now needs to be scaled to fit between 0 and 10, where 10 is the highest possible economic importance within the bounds of the exercise. The maximum possible economic importance is given when all end uses are assigned to the megasector with the highest GVA in a given year (in this case Mechanical Equipment with 182.41). Thus, the linear scaling for niobium is done by:

1. Dividing 108.10 by 182.41 = 0.59 (maximum possible is 1.0)
2. Multiplying the result by 10 yields the score for economic importance for niobium (5.9).

Similarly for lithium, the result is 0.55 (scaled 5.5)

Notice that dividing by the European GDP is not necessary because the figures are scaled to fit between 0 and 10 and the ranking is relative. Also, notice that the score has no units.

Supply data and supply risk

Production data for niobium are given below[a]. To move from fractional shares to a supply risk score, which is based on the Herfindahl-Hirschmann-Index (HHI), the square of the shares is needed[b]. For the original HHI, the sum of the squares is the value of interest. However, in the calculation of supply risk, the square of the shares are first multiplied by the scaled World Governance Index (WGI, see Annex C), leading to a "contribution to HHI-WGI", which is added to build the HHI_{WGI} used later. The procedure is analogous for the Environmental Performance Index (EPI, see Annex C). The values for WGI_{scaled} and EPI_{scaled} can be taken from Annex C.

Niobium - Production

Country	Share	$(Share*100)^2$	WGI_{scaled}	Contribution to HHI-WGI	EPI_{scaled}	Contribution to HHI-EPI
Brazil	0.92	8,454	4.7	39 989	4.2	35,756
Canada	0.07	49	1.8	86	3.9	192
Nigeria	0.01	1	7.3	4	6.2	4
Rwanda	0.00	0	5.4	0	6.2	0
Mozambique	0.00	0	5.6	0	5.7	0
Ethiopia	0.00	0	6.9	0	5.2	0
Burundi	0.00	0	7.4	0	5.9	0
DRC	0.00	0	8.3	0	5.7	0
				40,080		**35,952**

Lithium - Production

Country	Share	$(Share*100)^2$	WGI_{scaled}	Contribution to HHI-WGI	EPI_{scaled}	Contribution to HHI-EPI
Chile	0.48	2 263	2.6	5 833	4.5	10 108
Australia	0.22	483	1.7	843	4.3	2 097
Argentina	0.16	243	5.4	1 320	4.4	1 057
USA	0.07	45	2.5	113	4.3	194
China	0.06	36	6.2	223	5.8	209
Brazil	0.01	1	4.7	6	3.9	5
Portugal	0.01	1	3.1	4	4.2	5
				8 342		**13 675**

Notice that both HHI_{WGI} and HHI_{EPI} are in the range of 0 to 100 000[c]. Multiplying this by the fraction of total supply covered by primary resources (i.e. 100% minus end-of-life recycling input rate) and then by the weighted substitutability index gives a raw value of the supply risk for niobium:

1. Using WGI: $40080 \times (1 - 0.11) \times 0.69 \approx 24600$
2. Using EPI: $35952 \times (1 - 0.11) \times 0.69 \approx 22000$

Similarly, for lithium:

1. Using WGI: $8\,342 \times (1 - 0) \times 0.78 \approx 6\,500$
2. Using EPI: $13\,775 \times (1 - 0) \times 0.78 \approx 10\,700$

---

[a] Note that production data is available for all countries shown but the shares are < 1%. All countries are shown here for the sake of completeness.

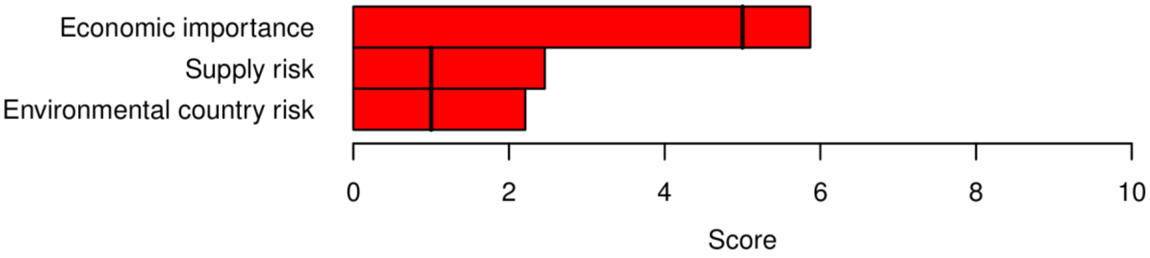
[b] For the calculation of the Herfindahl-Hirschmann-Index, the shares need to be in the range 0-100 instead of 0-1. Therefore, the fractional share is multiplied by 100 before taking the square of the value.

[c] In a monopoly situation, $100^2 = 10\,000$. This, multiplied by the worst possible WGI_{scaled} score (10) gives 100 000.

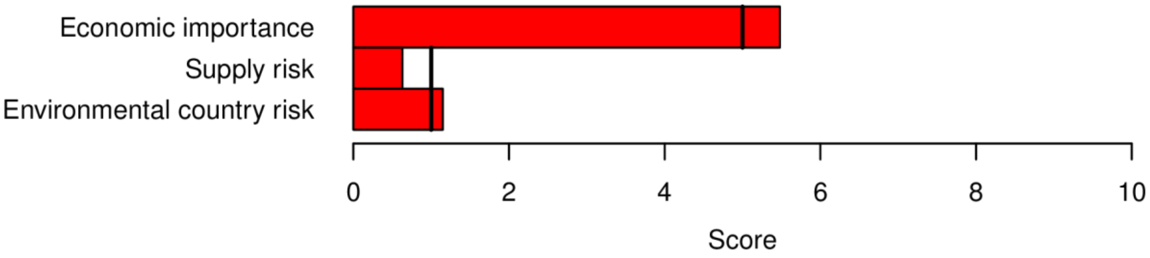
Now the only thing left to do is ensure that the values lie between 0 and 10 (linear scaling). For this, divide the results by 10 000[a] and round to the first decimal place. This yields scores for niobium of 2.5 and 2.2 based on WGI and EPI, respectively. For lithium, the values are 0.7 and 1.1, respectively.

The thresholds for the criticality assessment are set at 5 and 1 for economic importance and both supply risk measures. Therefore as niobium exceeds the economic importance threshold (5.6) and at least one of the supply risk measures (in this case both), it is considered a critical material. In the case of lithium the economic importance (5.5) exceeds the threshold, and EPI indicator (1.1) exceeds the supply risk threshold (1). In this case the WGI supply risk measure (0.7) does not exceed the threshold, however as one supply risk threshold is exceeded, as well as the economic importance lithium is considered critical.

Niobium – Results Chart



Lithium – Results Chart



---

[a] This changes the range of values from 0 to 100 000 to being from 0 to 10.

Annex E – Further Data and Detailed Results of Criticality Assessment

This Annex contains the following information: end uses, megasector assignment and substitution values, a summary of economic importance and supply risk calculations, a comparison of results for 2013 and 2010, and large format results charts.

End uses, megasector assignment and substitution values

Material	Application	Share	Megasector	Value (GVA)	Substitutability
Aluminium	Transport	37%	Transport-Road	147.4	0.7
Aluminium	Building	26%	Construction	104.4	0.5
Aluminium	Packaging	16%	Metals	164.6	0.7
Aluminium	Engineering	14%	MechEquip	182.4	0.7
Aluminium	Others	7%	Other	63.3	0.5
Antimony	Flame Retardants	52%	Chemicals	108.8	0.7
Antimony	Lead-acid batteries (automotive)	20%	Transport-Road	147.4	0.7
Antimony	Lead Alloys	11%	Metals	164.6	0.3
Antimony	Lead Alloys	11%	Metals	164.6	0.7
Antimony	Lead-acid batteries (other)	7%	Electrical	88.1	0.7
Barytes	Weighting agent in gas- and oil-well drilling fluids	95%	Oil	50.0	1.0
Barytes	Others (paints, plastics, rubber, automobile brake and clutch pads, automobile paint)	5%	Other	63.3	0.5
Bauxite	Aluminium production	86%	Metals	164.6	1.0
Bauxite	Nonmetallurgical uses	10%	Chemicals	108.8	0.5
Bauxite	Others	4%	Other	63.3	0.5
Bentonite	Pet litter	29%	Other	63.3	0.3
Bentonite	Foundry molding sands	24%	Metals	164.6	0.7
Bentonite	Pelletizing of iron ore	21%	Mining	4.5	0.7
Bentonite	Civil engineering	11%	Construction	104.4	0.5
Bentonite	Specialties	4%	Chemicals	108.8	0.7
Bentonite	Paper	4%	Paper	41.3	0.5
Bentonite	Food & wine production	4%	Food	165.0	0.7
Bentonite	Drilling fluids	2%	Oil	50.0	0.7
Beryllium	Mechanical equipment	25%	MechEquip	182.4	0.9
Beryllium	Electrical equipment and domestic appliances	20%	Electrical	88.1	0.9
Beryllium	Electronics & IT	20%	Electronics	104.9	0.7
Beryllium	Road transport	15%	Transport-Road	147.4	0.9
Beryllium	Aircraft, shipbuilding and trains	10%	Transport-Other	51.2	1.0
Beryllium	Others	4%	Other	63.3	0.5
Beryllium	Rubber, plastics and glass	3%	Plastic	98.1	0.7
Beryllium	Metals	3%	Metals	164.6	1.0
Borate	Glass	51%	Plastic	98.1	1.0
Borate	Frits & ceramics	14%	Construction	104.4	0.7
Borate	Agriculture	13%	Chemicals	108.8	1.0
Borate	Chemicals	8%	Chemicals	108.8	0.5
Borate	Metallurgy	5%	Metals	164.6	1.0
Borate	Construction materials	4%	Construction	104.4	0.7
Borate	Industrial fluids	2%	Chemicals	108.8	0.5
Borate	Other	2%	Other	63.3	0.5
Borate	Detergents	1%	Chemicals	108.8	0.7
Borate	Flame retardants	1%	Chemicals	108.8	0.3
Chromium	Stainless steel	88%	Metals	164.6	1.0
Chromium	Steel	9%	Metals	164.6	0.7

Material	Application	Share	Megasector	Value (GVA)	Substitutability
Chromium	Superalloys	2%	Metals	164.6	1.0
Chromium	Other	1%	Other	63.3	0.5
Clays	Ceramics	61%	Construction	104.4	1.0
Clays	Others	18%	Other	63.3	0.5
Clays	Paper	17%	Paper	41.3	0.3
Clays	Fiberglass	5%	Plastic	98.1	0.7
Cobalt	Batteries	30%	Electronics	104.9	0.8
Cobalt	Superalloys	19%	Metals	164.6	0.7
Cobalt	Hard Materials - Carbides, Diamond Tooling	13%	Metals	164.6	0.7
Cobalt	Pigments	9%	Chemicals	108.8	0.5
Cobalt	Catalysts	9%	Chemicals	108.8	0.7
Cobalt	Magnets	7%	Electrical	88.1	0.7
Cobalt	Hardfacing/HSS & Other Alloys	5%	Metals	164.6	0.7
Cobalt	Tyre Adhesives, Soaps, Driers (paint/ink)	5%	Other	63.3	0.7
Cobalt	Feedstuffs, Biotech, Anodising, Recording Media, Electrolysis	3%	Other	63.3	0.7
Coking coal	Steel production	90%	Metals	164.6	0.7
Coking coal	Other metallurgy & niche markets	10%	Metals	164.6	0.5
Copper	Electrical infrastructure and equipment	41%	Electrical	88.1	0.7
Copper	Construction	13%	Construction	104.4	0.3
Copper	Mechanical equipment	12%	MechEquip	182.4	0.7
Copper	Other	12%	Other	63.3	0.5
Copper	Automotive	10%	Transport-Road	147.4	0.7
Copper	Electronics & ICT	6%	Electronics	104.9	0.7
Copper	Transport, other	4%	Transport-Other	51.2	0.7
Diatomite	Filter aids	75%	Beverages	37.0	0.3
Diatomite	Absorbents	12%	Chemicals	108.8	0.5
Diatomite	Fillers	12%	Construction	104.4	0.3
Diatomite	Others	1%	Other	63.3	0.5
Feldspar	Glass	70%	Plastic	98.1	0.7
Feldspar	Pottery and other uses	30%	Other	63.3	0.3
Fluorspar	Hydrofluoric acid	52%	Chemicals	108.8	1.0
Fluorspar	Steel	25%	Metals	164.6	0.3
Fluorspar	Aluminium	18%	Metals	164.6	1.0
Fluorspar	Other	5%	Other	63.3	0.5
Gallium	Integrated circuits	41%	Electronics	104.9	0.7
Gallium	LED	25%	Electronics	104.9	0.7
Gallium	Alloys, Batteries and Magnets	17%	Metals	164.6	0.5
Gallium	Solar	17%	Electronics	104.9	0.3
Germanium	Fibre optic	30%	Electronics	104.9	1.0
Germanium	Catalysts (polymers)	25%	Plastic	98.1	0.7
Germanium	Infrared optic	25%	Electronics	104.9	1.0
Germanium	Parts for electrical and solar equipment	15%	Electronics	104.9	0.7
Germanium	Others	5%	Other	63.3	0.5
Gold	Jewelry	82%	Other	63.3	0.7
Gold	Electronics	13%	Electronics	104.9	1.0
Gold	Other	4%	Other	63.3	0.5
Gold	Dental	2%	Pharma	85.9	0.3
Gypsum	Wallboard and plaster products	90%	Construction	104.4	0.7
Gypsum	Cement production and agricultural applications	6%	Other	63.3	0.9
Gypsum	Others	4%	Other	63.3	0.5
Hafnium	Super Alloys	45%	Metals	164.6	0.3
Hafnium	Nuclear Control Rods	13%	Electrical	88.1	0.3
Hafnium	Plasma Cutting Tips	13%	MechEquip	182.4	0.5
Hafnium	Optical Coatings	11%	Electronics	104.9	0.5
Hafnium	Catalysts	7%	Chemicals	108.8	0.5
Hafnium	CVD/Targets	7%	Chemicals	108.8	0.5

Material	Application	Share	Megasector	Value (GVA)	Substitutability
Hafnium	Special Steels	3%	Metals	164.6	0.5
Hafnium	Electronics	1%	Electronics	104.9	0.5
Indium	Flat panel displays	56%	Electronics	104.9	1.0
Indium	Solders	10%	Electrical	88.1	0.7
Indium	Photovoltaics	8%	Electronics	104.9	0.7
Indium	Others	8%	Other	63.3	0.5
Indium	Thermal interface materials	6%	Electronics	104.9	0.7
Indium	Batteries (alkaline)	5%	Electronics	104.9	0.3
Indium	Alloys/compounds	4%	Metals	164.6	0.3
Indium	Compound semiconductors & LEDs	3%	Electronics	104.9	0.7
Iron ore	Steel: Construction	26%	Construction	104.4	1.0
Iron ore	Steel: Automotive	16%	Transport-Road	147.4	0.7
Iron ore	Steel: Mechanical engineering	14%	MechEquip	182.4	0.7
Iron ore	Steel: Tubes	12%	Metals	164.6	0.7
Iron ore	Steel: Metal goods	12%	Metals	164.6	1.0
Iron ore	Steel: Structural	11%	Construction	104.4	1.0
Iron ore	Steel: Domestic applicances	4%	Electrical	88.1	0.7
Iron ore	Steel: Misc	3%	Metals	164.6	0.5
Iron ore	Other	2%	Other	63.3	0.5
Iron ore	Steel: Shipyard	1%	Transport-Other	51.2	1.0
Limestone	Paper (bleaching)	22%	Paper	41.3	0.3
Limestone	Iron & steel	21%	Metals	164.6	1.0
Limestone	Building materials (incl. Sealants and plasters)	19%	Construction	104.4	1.0
Limestone	Environmental protection (flue gas, drinking water, sewage treatment)	9%	Construction	104.4	1.0
Limestone	Paints & coatings	8%	Chemicals	108.8	0.3
Limestone	Agriculture (fertilisers)	8%	Chemicals	108.8	1.0
Limestone	Plastics and rubber	5%	Plastic	98.1	0.3
Limestone	Chemical	5%	Chemicals	108.8	1.0
Limestone	Non-ferrous	2%	Metals	164.6	1.0
Limestone	Others	1%	Other	63.3	0.5
Lithium	Ceramics and glass	30%	Plastic	98.1	1.0
Lithium	Batteries	22%	Electronics	104.9	1.0
Lithium	Other	22%	Other	63.3	0.5
Lithium	Lubricating grease	11%	Chemicals	108.8	0.7
Lithium	Continuous casting	4%	Metals	164.6	0.7
Lithium	Gas and air treatment	4%	MechEquip	182.4	0.3
Lithium	Synthetic rubbers and plastics	3%	Plastic	98.1	0.7
Lithium	Aluminium smelting	2%	Metals	164.6	0.3
Lithium	Pharmaceuticals	2%	Pharma	85.9	0.3
Magnesite	Refractory others	83%	Metals	164.6	0.7
Magnesite	Environmental	6%	Other	63.3	0.7
Magnesite	Agricultural (animal feed & fertilizers)	5%	Chemicals	108.8	1.0
Magnesite	Others	5%	Other	63.3	0.8
Magnesite	Cement-industry	1%	Construction	104.4	0.7
Magnesium	aluminum-based alloys (packaging, transportation, other applications)	40%	Beverages	37.0	0.7
Magnesium	Magnesium die-casting	39%	Transport-Road	147.4	0.7
Magnesium	Steel desulphurisation	12%	Metals	164.6	0.3
Magnesium	Others	7%	Other	63.3	0.5
Magnesium	Nodular cast iron	1%	Metals	164.6	0.7
Manganese	Construction	25%	Construction	104.4	1.0
Manganese	Automotive	14%	Transport-Road	147.4	1.0
Manganese	Mechanical Engineering	13%	MechEquip	182.4	1.0
Manganese	Structural steelworks	11%	MechEquip	182.4	1.0
Manganese	Tubes	10%	MechEquip	182.4	1.0
Manganese	Metalware	10%	Metals	164.6	1.0

Material	Application	Share	Megasector	Value (GVA)	Substitutability
Manganese	Non-steel alloys	6%	Metals	164.6	0.7
Manganese	Other	5%	Other	63.3	0.5
Manganese	Domestic appliances	4%	Electrical	88.1	1.0
Manganese	Batteries (cathodes)	2%	Electronics	104.9	0.0
Manganese	Shipyards	1%	Transport-Other	51.2	1.0
Molybdenum	Oil and Gas	18%	Oil	50.0	1.0
Molybdenum	Chemical/Petrochemical	15%	Chemicals	108.8	1.0
Molybdenum	Automotive	14%	Transport-Road	147.4	1.0
Molybdenum	Mechanical Engineering	12%	MechEquip	182.4	1.0
Molybdenum	Power Generation	8%	Electrical	88.1	1.0
Molybdenum	Process Industry	8%	MechEquip	182.4	1.0
Molybdenum	Other Transportation	7%	Transport-Other	51.2	1.0
Molybdenum	Others	7%	Other	63.3	0.5
Molybdenum	Building / Construction	6%	Construction	104.4	0.3
Molybdenum	Aerospace & Defence	3%	Transport-Other	51.2	1.0
Molybdenum	Electronics & Medical	2%	Electronics	104.9	1.0
Natural Graphite	Electrodes	34%	Metals	164.6	1.0
Natural Graphite	Others	24%	Other	63.3	0.5
Natural Graphite	Refractories	20%	Metals	164.6	0.7
Natural Graphite	Lubricants	6%	Chemicals	108.8	0.3
Natural Graphite	Foundries	5%	Metals	164.6	0.7
Natural Graphite	Batteries	4%	Electronics	104.9	0.3
Natural Graphite	Graphite Shapes	4%	MechEquip	182.4	1.0
Natural Graphite	Friction Products	2%	Transport-Road	147.4	0.7
Natural Graphite	Recarburising	1%	Metals	164.6	0.3
Natural rubber	Tyres (land vehicles) & other automotive	87%	Transport-Road	147.4	0.9
Natural rubber	General (non-automotive)	12%	Plastic	98.1	0.3
Natural rubber	Tyres (aircraft)	1%	Transport-Other	51.2	1.0
Nickel	Stainless steel	61%	Metals	164.6	0.7
Nickel	Nickel base alloys	12%	Metals	164.6	0.7
Nickel	Alloy steel	9%	Metals	164.6	0.7
Nickel	Plating	7%	Metals	164.6	1.0
Nickel	Other	5%	Other	63.3	0.5
Nickel	Copper base alloys	2%	Metals	164.6	1.0
Niobium	Steel: Structural	31%	Construction	104.4	0.7
Niobium	Steel: Automotive	28%	Transport-Road	147.4	0.7
Niobium	Steel: Pipeline	24%	Oil	50.0	0.7
Niobium	Superalloys	8%	Metals	164.6	0.7
Niobium	Others	6%	Other	63.3	0.5
Niobium	Steel: Chemical industry	3%	MechEquip	182.4	0.7
Perlite	Formed products	53%	Other	63.3	0.5
Perlite	Fillers	15%	Construction	104.4	0.3
Perlite	Horticultural aggregate	14%	Food	165.0	0.3
Perlite	Filter aid	10%	Beverages	37.0	0.3
Perlite	Others	5%	Other	63.3	0.5
Perlite	Plaster aggregate	1%	Construction	104.4	0.3
Perlite	High-temperature insulation	1%	Construction	104.4	0.3
Perlite	Concrete aggregate	1%	Construction	104.4	0.3
Phosphate Rock	Wet-process phosphoric acid and superphosphoric acid (used as intermediate feedstocks in the manufacture of granular and liquid ammonium phosphate fertilizers and animal feed supplements)	95%	Chemicals	108.8	1.0
Phosphate Rock	Others	5%	Other	63.3	0.5
PGMs	Autocatalyst	55%	Transport-Road	147.4	1.0
PGMs	Jewellery	17%	Other	63.3	0.3
PGMs	Electronics	10%	Electronics	104.9	1.0
PGMs	Chemical & Electrochemical	7%	Chemicals	108.8	1.0

Material	Application	Share	Megasector	Value (GVA)	Substitutability
PGMs	Others	6%	Other	63.3	0.5
PGMs	Medical alloys	3%	Metals	164.6	0.3
PGMs	Glass	1%	Plastic	98.1	1.0
PGMs	Petroleum Production	1%	Refining	29.2	1.0
Potash	Fertilisers	92%	Food	165.0	0.3
Potash	Others	8%	Other	63.3	0.5
Pulpwood	Graphic paper	44%	Paper	41.3	0.7
Pulpwood	Packaging papers	43%	Paper	41.3	0.7
Pulpwood	Household & sanitary	8%	Paper	41.3	0.7
Pulpwood	Other papers	5%	Paper	41.3	0.7
REE (Heavy)	Phosphors: lighting	45%	Electrical	88.1	0.7
REE (Heavy)	Phosphors: displays	14%	Electronics	104.9	0.7
REE (Heavy)	Magnets	12%	Electrical	88.1	0.7
REE (Heavy)	Chemical (other)	10%	Chemicals	108.8	1.0
REE (Heavy)	Ceramics: electronics	7%	Electronics	104.9	1.0
REE (Heavy)	Phosphors: other	5%	Chemicals	108.8	1.0
REE (Heavy)	Glass	4%	Plastic	98.1	1.0
REE (Heavy)	Metallurgy	3%	Metals	164.6	0.3
REE (Light)	Magnets	21%	Electrical	88.1	0.7
REE (Light)	Glass Polishing	17%	Plastic	98.1	0.7
REE (Light)	FCCs	14%	Refining	29.2	1.0
REE (Light)	Metallurgy	12%	Metals	164.6	0.3
REE (Light)	Batteries (NiMH)	9%	Electrical	88.1	0.3
REE (Light)	Autocatalyst	7%	Transport-Road	147.4	0.7
REE (Light)	Glass	7%	Plastic	98.1	1.0
REE (Light)	Others	7%	Other	63.3	0.5
REE (Light)	Phosphors	3%	Electronics	104.9	0.7
REE (Light)	Ceramics	2%	Construction	104.4	1.0
REE (Light)	Catalyst	1%	Chemicals	108.8	1.0
Rhenium	Super alloys (aerospace)	63%	Transport-Other	51.2	1.0
Rhenium	Super alloys (gas turbines)	13%	MechEquip	182.4	1.0
Rhenium	Catalysts	9%	Chemicals	108.8	0.7
Rhenium	Others	6%	Other	63.3	0.5
Rhenium	Automotive Parts	5%	Transport-Road	147.4	1.0
Rhenium	Petroleum Production	2%	Refining	29.2	1.0
Rhenium	Tools	2%	MechEquip	182.4	1.0
Sawn Softwood	Construction	80%	Construction	104.4	0.7
Sawn Softwood	Furniture	20%	Other	63.3	0.7
Scandium	Al-alloys: Sport	85%	Other	63.3	0.3
Scandium	Lighting	10%	Electronics	104.9	0.7
Scandium	Fuel cells	5%	Electronics	104.9	0.3
Selenium	Metallurgy	40%	Metals	164.6	0.3
Selenium	Glass	25%	Plastic	98.1	0.7
Selenium	Chemicals and Pigments	10%	Chemicals	108.8	0.3
Selenium	Agriculture	10%	Chemicals	108.8	1.0
Selenium	Electronics	10%	Electronics	104.9	0.3
Selenium	Others	5%	Other	63.3	0.5
Silica sand	Glass (flat & container glass)	38%	Plastic	98.1	1.0
Silica sand	Building materials (cement, concrete blocks, glues for tiles, etc.)	30%	Construction	104.4	1.0
Silica sand	Foundry	17%	Metals	164.6	1.0
Silica sand	Others (fibreglass, chemicals, abrasives, leasure, filtration)	15%	Other	63.3	0.5
Silicon metal	Chemicals and Pigments	54%	Chemicals	108.8	0.7
Silicon metal	Metallurgy	38%	Metals	164.6	1.0
Silicon metal	Electronics	8%	Electronics	104.9	0.7
Silver	Jewellery, Silverware, Coins and Medals	37%	Other	63.3	0.7
Silver	Electronics	22%	Electronics	104.9	1.0

Material	Application	Share	Megasector	Value (GVA)	Substitutability
Silver	Others	17%	Other	63.3	0.5
Silver	Photography	8%	Chemicals	108.8	0.3
Silver	Brazing Alloys & Solders	7%	Metals	164.6	0.7
Silver	Photovoltaics	6%	Electronics	104.9	1.0
Silver	Ethylene Oxide industry	3%	Chemicals	108.8	0.7
Talc	Plastics	31%	Plastic	98.1	0.3
Talc	Paint	21%	Chemicals	108.8	0.3
Talc	Paper	15%	Paper	41.3	0.3
Talc	Agriculture	12%	Chemicals	108.8	0.7
Talc	Ceramics	9%	Construction	104.4	0.3
Talc	Rubber	4%	Plastic	98.1	0.7
Talc	Others	4%	Other	63.3	0.5
Talc	Cosmetics & pharmaceuticals	3%	Pharma	85.9	0.7
Talc	Food	1%	Food	165.0	0.7
Tantalum	Capacitors	40%	Electronics	104.9	0.3
Tantalum	Superalloys	21%	Metals	164.6	0.7
Tantalum	Sputtering targets	12%	Electronics	104.9	1.0
Tantalum	Mill products	11%	MechEquip	182.4	0.7
Tantalum	Carbides	10%	MechEquip	182.4	0.3
Tantalum	Chemicals	6%	Chemicals	108.8	1.0
Tellurium	Photovoltaics	40%	Electronics	104.9	0.3
Tellurium	Thermoelectrics	30%	Electronics	104.9	0.7
Tellurium	Metallurgy	15%	Metals	164.6	0.3
Tellurium	Others	10%	Other	63.3	0.5
Tellurium	Rubber Formulation	5%	Plastic	98.1	0.3
Tin	Solder (eletronics)	45%	Electronics	104.9	0.7
Tin	Tinplate (packaging)	16%	Metals	164.6	0.3
Tin	Chemicals and Pigments	15%	Chemicals	108.8	0.7
Tin	Solder (industrial)	9%	MechEquip	182.4	0.7
Tin	Others	8%	Other	63.3	0.5
Tin	Brass and Bronze	5%	Metals	164.6	0.3
Tin	Float Glass	2%	Plastic	98.1	0.7
Titanium	Paint	56%	Chemicals	108.8	0.3
Titanium	Plastic	27%	Plastic	98.1	0.3
Titanium	Paper	9%	Paper	41.3	0.3
Titanium	Welding rod coatings and manufacturing carbides, chemicals and metal	5%	Metals	164.6	0.7
Titanium	Others	3%	Other	63.3	0.7
Tungsten	Cemented carbides	60%	MechEquip	182.4	0.7
Tungsten	Fabricated products	17%	Electrical	88.1	0.7
Tungsten	Alloy steels (mainly tool steel, >80%)	13%	MechEquip	182.4	0.7
Tungsten	Superalloys	6%	Metals	164.6	0.7
Tungsten	Tungsten alloys	4%	MechEquip	182.4	0.7
Vanadium	Full alloy incl tool steel	32%	MechEquip	182.4	0.5
Vanadium	HSLA steel long products	25%	Metals	164.6	0.3
Vanadium	HSLA steel plate	18%	Metals	164.6	0.3
Vanadium	Carbon steel	13%	Metals	164.6	0.7
Vanadium	Titanium alloys	5%	Metals	164.6	1.0
Vanadium	Chemicals	4%	Chemicals	108.8	0.3
Vanadium	Other iron & steel	2%	Metals	164.6	0.5
Vanadium	Other (mainly batteries)	1%	Other	63.3	0.5
Zinc	Galvanizing	50%	Metals	164.6	0.7
Zinc	Brass and Bronze	17%	Metals	164.6	0.5
Zinc	Zinc Alloying	17%	Metals	164.6	0.7
Zinc	Chemicals	6%	Chemicals	108.8	1.0
Zinc	Zinc semi-manufactures	6%	Metals	164.6	0.5
Zinc	Miscellaneous	4%	Other	63.3	0.5

Economic importance and supply risk calculations

Material	Economic Importance (Raw)	Economic Importance (Scaled)	HHI	HHI-WGI (scaled)	HHI-EPI (scaled)	Substitutability Index	Recycling Input Rate (EoL %)	Supply Risk (WGI)	Supply Risk (EPI)
Aluminium	138	7.57	1781	1.0512	1.0321	0.63	35%	0.43	0.42
Antimony	129	7.07	7458	4.6108	4.3069	0.62	11%	2.5	2.4
Barytes	51	2.8	2941	1.7755	1.7498	0.98	0%	1.74	1.71
Bauxite	156	8.55	1886	0.6179	0.8922	0.93	0%	0.57	0.83
Bentonite	84	4.61	1620	0.6703	0.7858	0.55	0%	0.37	0.43
Beryllium	123	6.74	8242	2.113	3.4349	0.85	19%	1.45	2.36
Borate	103	5.65	2624	1.0752	1.2605	0.88	0%	0.95	1.11
Chromium	163	8.94	2503	1.2132	1.5885	0.96	13%	1.01	1.33
Clays	87	4.77	1046	0.3403	0.4298	0.78	0%	0.27	0.34
Cobalt	122	6.69	3361	2.7261	1.9033	0.71	16%	1.63	1.14
Coking coal	164	8.99	3049	1.73	1.7559	0.68	0%	1.18	1.19
Copper	105	5.76	1452	0.4407	0.6591	0.62	20%	0.22	0.33
Diatomite	55	3.02	2108	0.7333	0.9478	0.33	0%	0.24	0.31
Feldspar	88	4.82	1315	0.6083	0.5787	0.58	0%	0.35	0.34
Fluorspar	131	7.18	3535	2.1484	2.0805	0.8	0%	1.72	1.66
Gallium	115	6.3	4985	3.0361	2.9448	0.6	0%	1.82	1.77
Germanium	101	5.54	4009	2.2513	2.2819	0.86	0%	1.94	1.96
Gold	69	3.78	606	0.2812	0.3181	0.72	25%	0.15	0.17
Gypsum	101	5.54	1144	0.6735	0.6255	0.7	1%	0.47	0.43
Hafnium	143	7.84	4414	1.1334	1.5944	0.38	0%	0.43	0.61
Indium	102	5.59	3757	2.1962	2.166	0.82	0%	1.8	1.78
Iron	135	7.4	1655	0.7653	0.8669	0.84	22%	0.5	0.57
Limestone	105	5.76	1080	0.5076	0.5558	0.75	0%	0.38	0.42
Lithium	100	5.48	3073	0.8342	1.3506	0.78	0%	0.65	1.05
Magnesite	151	8.28	4872	2.9927	2.887	0.72	0%	2.15	2.08
Magnesium	100	5.48	7439	4.5963	4.4354	0.64	14%	2.53	2.44
Manganese	142	7.78	1297	0.5707	0.7147	0.94	19%	0.43	0.54
Molybdenum	108	5.92	2270	1.1276	1.2187	0.92	17%	0.86	0.93
Natural Graphite	135	7.4	4979	3.0597	2.9688	0.72	0%	2.2	2.14
Natural Rubber	141	7.73	1909	1.0899	0.8695	0.83	0%	0.9	0.72
Nickel	161	8.83	1069	0.5215	0.4945	0.68	32%	0.24	0.23
Niobium	107	5.87	8504	4.008	3.5952	0.69	11%	2.46	2.21
Perlite	83	4.55	1882	0.6764	0.7673	0.42	0%	0.28	0.32
Phosphate Rock	106	5.81	1995	1.1147	1.1171	0.98	0%	1.09	1.09
PGMs	120	6.58	4542	2.1929	2.8387	0.83	35%	1.18	1.53
Potash	157	8.61	1576	0.6599	0.7001	0.32	0%	0.21	0.22
Pulpwood	41	2.25	1160	0.352	0.4982	0.7	51%	0.12	0.17
REE (Heavy)	98	5.37	9807	6.0644	5.6647	0.77	0%	4.67	4.36
REE (Light)	95	5.21	7598	4.6753	4.5237	0.67	0%	3.13	3.03
Rhenium	82	4.5	4092	1.0931	1.8093	0.94	13%	0.89	1.48
Sawn Softwood	97	5.32	763	0.2412	0.3271	0.70	9%	0.15	0.21
Scandium	69	3.78	5350	3.3144	3.162	0.34	1%	1.12	1.06
Selenium	126	6.91	1001	0.4144	0.4629	0.48	5%	0.19	0.21
Silica sand	105	5.76	1608	0.4606	0.6522	0.92	24%	0.32	0.46
Silicon	130	7.13	3397	2.0139	1.9632	0.81	0%	1.63	1.59
Silver	87	4.77	2137	1.335	1.147	0.72	24%	0.73	0.63
Talc	93	5.1	1260	0.6592	0.689	0.39	0%	0.26	0.27
Tantalum	135	7.40	2486	1.1751	1.1563	0.55	4%	0.62	0.61
Tellurium	109	5.98	1061	0.441	0.4874	0.44	0%	0.19	0.21
Tin	123	6.74	2536	1.5399	1.4584	0.60	11%	0.82	0.78
Titanium	101	5.54	1355	0.4307	0.6832	0.33	6%	0.13	0.21
Tungsten	165	9.05	7300	4.5132	4.3548	0.70	37%	1.99	1.92
Vanadium	166	9.1	3230	1.7854	1.9557	0.46	0%	0.82	0.9
Zinc	158	8.66	1390	0.7457	0.779	0.66	8%	0.45	0.47

Comparison of 2010 and 2013 studies

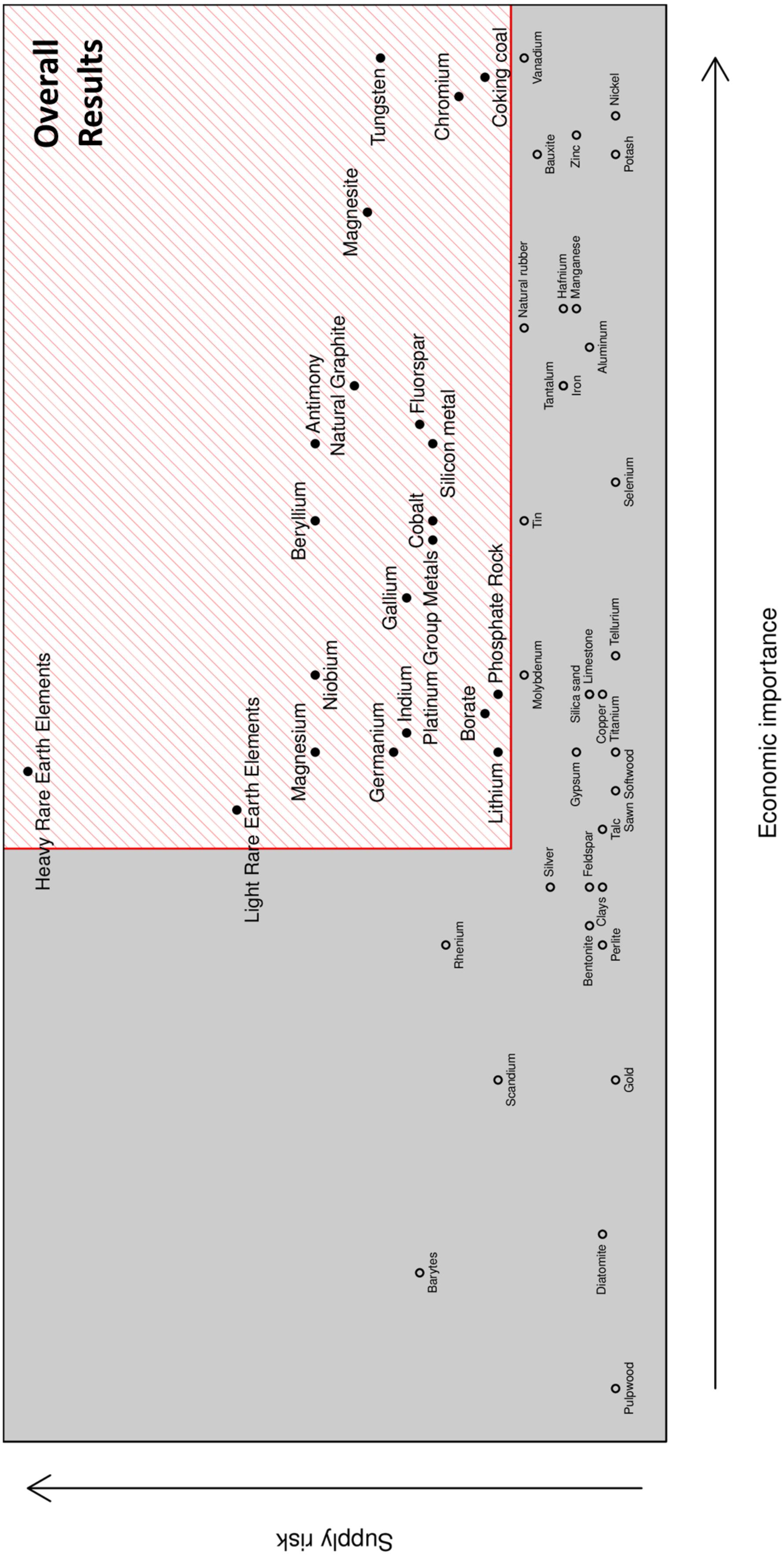
Raw Material	2010				2013			
	EI	SR (WGI)	SR (EPI)	Classification	EI	SR (WGI)	SR (EPI)	Classification
Aluminium	8.88	0.20	0.23	non-critical	7.57	0.43	0.41	non-critical
Antimony	5.84	2.56	2.39	**critical**	7.07	2.54	2.38	**critical**
Barytes	3.68	1.67	1.47	non-critical	2.80	1.74	1.67	non-critical
Bauxite	9.51	0.26	0.58	non-critical	8.55	0.57	0.81	non-critical
Bentonite	5.48	0.34	0.36	non-critical	4.61	0.37	0.44	non-critical
Beryllium	6.17	1.32	1.91	**critical**	6.74	1.45	2.47	**critical**
Borate	5.01	0.60	0.60	non-critical	5.65	0.95	1.16	**critical**
Chromium	9.92	0.80	0.86	non-critical	8.94	1.01	1.36	**critical**
Clays	4.44	0.30	0.36	non-critical	4.77	0.27	0.34	non-critical
Cobalt	7.24	1.06	0.77	**critical**	6.69	1.63	1.05	**critical**
Coking coal					8.99	1.18	1.16	**critical**
Copper	5.71	0.21	0.20	non-critical	5.76	0.22	0.33	non-critical
Diatomite	3.73	0.34	0.39	non-critical	3.02	0.24	0.32	non-critical
Feldspar	5.19	0.23	0.21	non-critical	4.82	0.35	0.34	non-critical
Fluorspar	7.50	1.63	1.47	**critical**	7.18	1.72	1.61	**critical**
Gallium	6.50	2.47	2.18	**critical**	6.30	1.82	1.71	**critical**
Germanium	6.28	2.73	2.59	**critical**	5.54	1.94	1.92	**critical**
Gold					3.78	0.15	0.17	non-critical
Gypsum	5.04	0.36	0.34	non-critical	5.54	0.47	0.40	non-critical
Hafnium					7.84	0.43	0.63	non-critical
Indium	6.71	2.02	1.73	**critical**	5.59	1.80	1.72	**critical**
Iron Ore	8.11	0.35	0.36	non-critical	7.40	0.50	0.55	non-critical
Limestone	5.95	0.73	0.70	non-critical	5.76	0.38	0.41	non-critical
Lithium	5.59	0.73	0.87	non-critical	5.48	0.63	1.15	**critical**
Magnesite	8.90	0.86	0.97	non-critical	8.28	2.15	2.01	**critical**
Magnesium	6.45	2.62	2.19	**critical**	5.48	2.53	2.36	**critical**
Manganese	9.80	0.45	0.43	non-critical	7.78	0.43	0.54	non-critical
Molybdenum	8.89	0.47	0.52	non-critical	5.92	0.86	0.92	non-critical
Natural Graphite	8.68	1.27	1.45	**critical**	7.40	2.20	2.07	**critical**
Natural rubber					7.73	0.90	0.70	non-critical
Nickel	9.54	0.27	0.24	non-critical	8.83	0.24	0.23	non-critical
Niobium	8.95	2.80	1.98	**critical**	5.87	2.46	2.04	**critical**
Perlite	4.20	0.31	0.30	non-critical	4.55	0.28	0.33	non-critical
Phosphate Rock					5.81	1.09	1.08	**critical**
PGMs	6.68	3.63	1.37	**critical**	6.58	1.18	1.56	**critical**
Potash					8.61	0.21	0.23	non-critical
Pulpwood					2.25	0.12	0.17	non-critical
REE (Heavy)*	5.78	4.86	4.34	**critical**	5.37	4.67	4.36	**critical**
REEs (Light)*	5.78	4.86	4.34	**critical**	5.21	3.13	3.03	**critical**
Rhenium	7.72	0.82	0.81	non-critical	4.50	0.89	1.50	non-critical
Sawn Softwood				non-critical	5.32	0.15	0.20	non-critical
Scandium*	5.78	4.86	4.34	**critical**	3.78	1.12	1.03	non-critical
Selenium					6.91	0.19	0.21	non-critical
Silica sand	5.83	0.18	0.23	non-critical	5.76	0.32	0.44	non-critical
Silicon metal					7.13	1.63	1.54	**critical**
Silver	5.07	0.27	0.21	non-critical	4.77	0.73	0.63	non-critical
Talc	4.02	0.30	0.21	non-critical	5.10	0.26	0.26	non-critical
Tantalum	7.38	1.13	0.73	**critical**	7.40	0.62	0.61	non-critical

Raw Material	2010					2013			
	EI	SR (WGI)	SR (EPI)	Classification		EI	SR (WGI)	SR (EPI)	Classification
Tellurium	7.90	0.56	0.35	non-critical		5.98	0.19	0.19	non-critical
Tin						6.74	0.89	0.78	non-critical
Titanium	5.38	0.13	0.16	non-critical		5.54	0.13	0.21	non-critical
Tungsten	8.75	1.81	1.42	**critical**		9.05	1.99	1.86	**critical**
Vanadium	9.71	0.73	0.67	non-critical		9.10	0.82	0.90	non-critical
Zinc	9.40	0.40	0.16	non-critical		8.66	0.45	0.46	non-critical

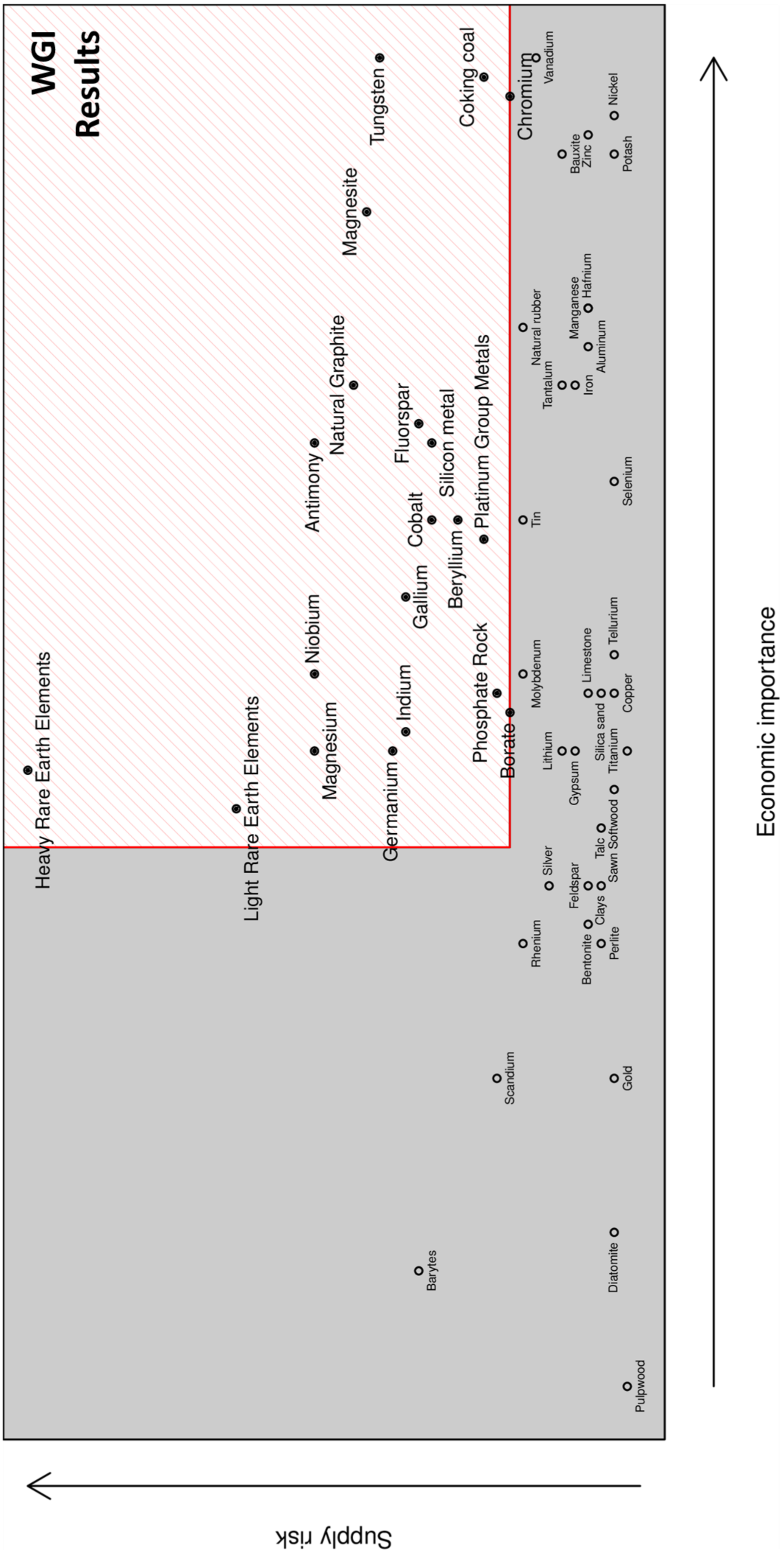
*Heavy Rare Earth Elements, Light Rare Earth Elements, and Scandium were considered together (as Rare Earth Elements) in the 2010 exercise.

Large format results and supply charts

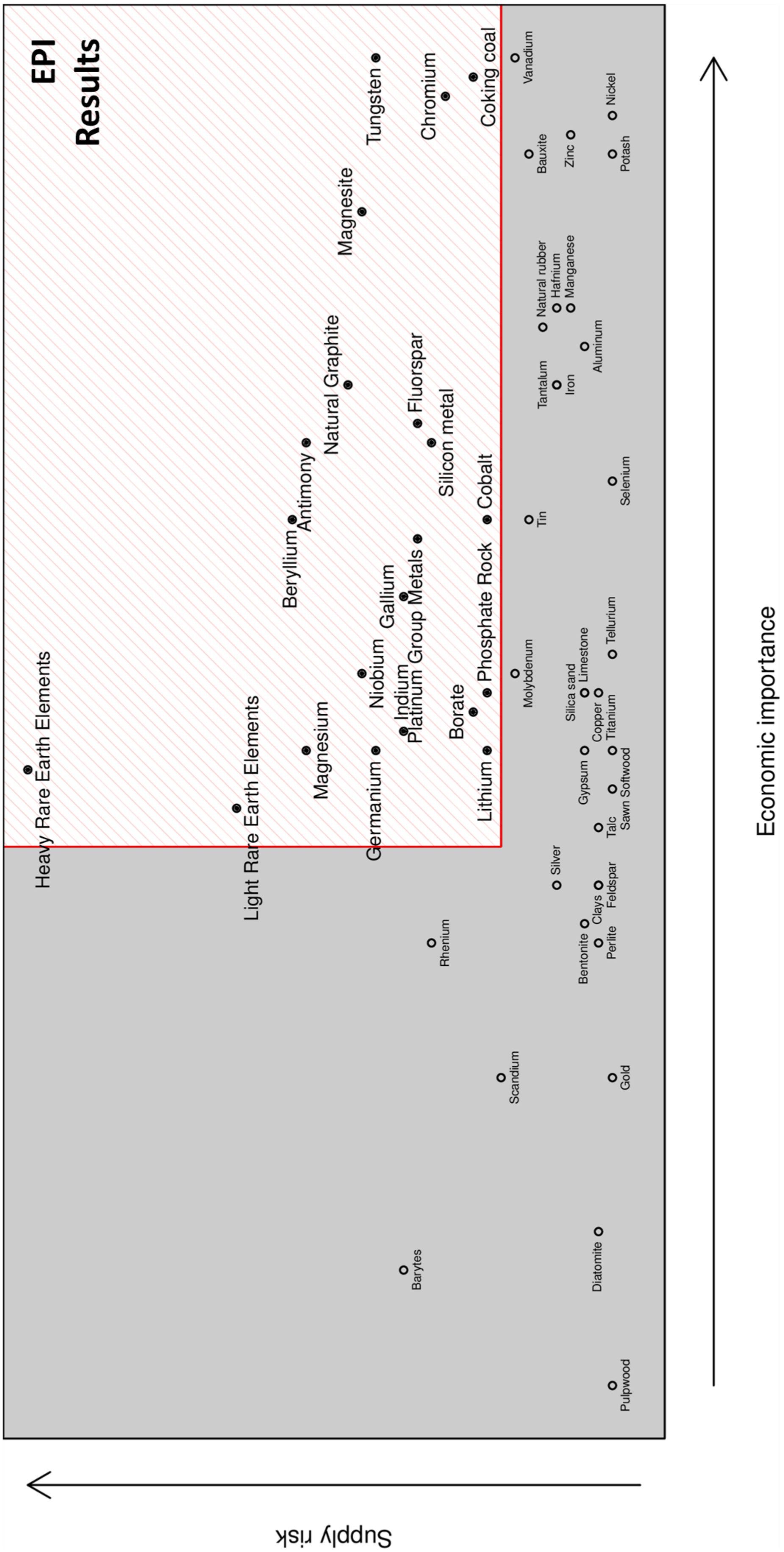
Overall results, using highest value for supply risk for each material



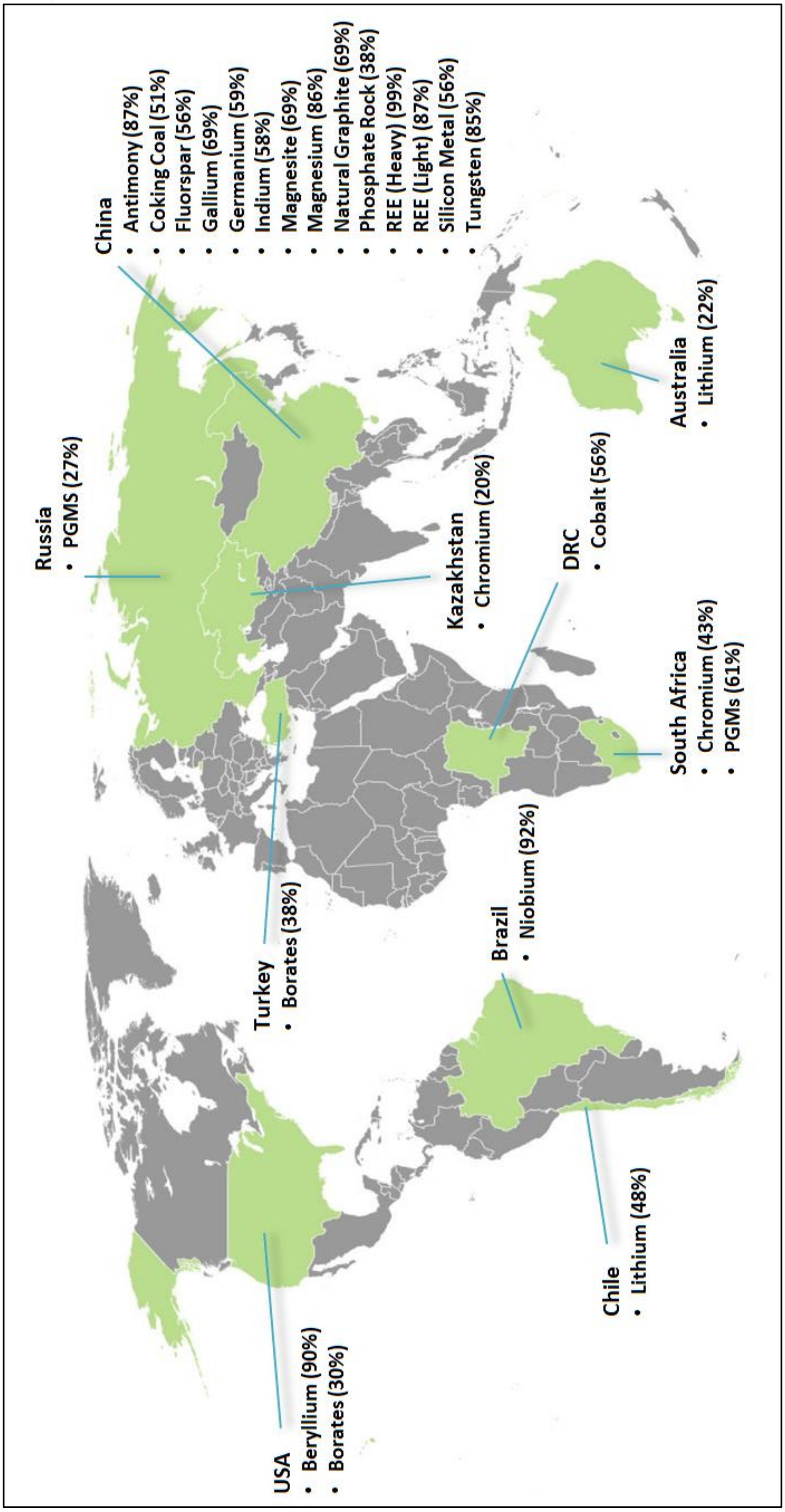
Analysis using WGI supply risk value for each material



Analysis using EPI supply risk value for each material



Major suppliers of raw materials



Annex F – Comparison with Other Methodologies

Materials security and materials criticality have been of growing interest to researchers, governments and other organisations due to increasing concerns over access to raw materials. As a result a variety of criticality studies have been published, each seeking to evaluate the criticality of a group of materials in relation to each other. These studies may consider materials in different contexts (e.g. based on territory, organisation or technological application), evaluate different groups of materials, use different criticality indicators, and have different methodologies altogether. As a consequence there is no universally agreed approach to assessing criticality and a tailored approach is required for each circumstance. Seven studies have been identified from within the last four years as being of most relevance to this study (Table 35). These represent a cross section of different study types and approaches.

Whilst the aims and scopes of these studies do vary, they all apply a selection of indicators to a group of materials to identify a list of critical materials. For each of these studies an analysis of their methodologies has been carried out to compare their approach to the EU methodology.

Table 35: List of criticality studies selected for review

No.	Author	Report Title	Year
1	Graedel *et al*	Methodology of Metal Criticality Determination	2011
2	EU JRC	Critical Metals in the Path towards the decarbonisation of the EU Energy Sector	2013
3	US DoE	Critical Materials Strategy	2011
4	Öko-Institute	Critical Metals for Future Sustainable Technologies and their Recycling Potential	2010
5	Korean Gov’t	Plans for Stable Procurement of Rare Metals	2010
6	GE	Research Priorities for More Efficient Use of Critical Materials from a U.S. Corporate Perspective	2010
7	Fraunhofer & IZT	Raw Materials for Emerging Technologies	2009

Materials security and materials criticality have been of growing interest to researchers, governments and other organisations due to increasing concerns over access to raw materials. As a result a variety of criticality studies have been published, each seeking to evaluate the criticality of a group of materials in relation to each other. These studies may consider materials in different contexts (e.g. based on territory, organisation, technological application or globally), evaluate different groups of materials, use different criticality indicators, and have different methodologies altogether. As a consequence there is no universally agreed approach to assessing criticality and a tailored approach is required for each circumstance. Seven studies have been identified from within the last four years as being of most relevance to this study, Table 35. These represent a cross section of different study types and approaches.

Whilst the aims and scopes of these studies do vary, they all apply a selection of indicators to a group of materials to identify a list of critical materials. For each of these studies an analysis of their methodologies has been carried out to compare their approach to the EU methodology.

Table 36: Criteria used by selected criticality studies. For comparison, criteria used for Critical Raw Materials for the EU is shown in the top line.

Study No.	Author	Source Organisation	Year	Scope	Materials in scope	Critical Materials	Supply					Demand			Others	
							Physical scarcity	Production limitations	Supply Concentration	Political Risk	Import dependency	Importance to economy (sector)	Demand growth	Price fluctuations	Environmental Risk	Temporal Differences
	EC DG ENTR	EC DG ENTR	2010	Territorial	41‡	14‡			X	X		X			X	
1	Graedel *et al*	ACS	2011	Global	N/A	N/A	(X)	(X)	X	X		X			X	X
2	Oakdene Hollins Fraunhofer ISI	EU JRC	2013	Technology	60	12		X	X	X		X	X			X
3	US DoE	US Office of Policy and inter	2011	Technology	16	7	X	X	X	X		X	X			X
4	Öko-Institute	UNEP	2010	Technology	N/A	11†	X	X	X				X			
5	Korean Gov't	US DoE*	2010	Territorial	56‡	11‡	X	X		X	X	X	X	X		
6	General Electric Company	General Electric Company	2010	Business	24	7	X	X		X		X	X	X		
7	Fraunhofer & IZT	BMWi	2009	Technology	N/A	15			X	X		X	X			

*Summary information gathered from US DoE rather than Korean Government

‡PGMs and REE included as groups

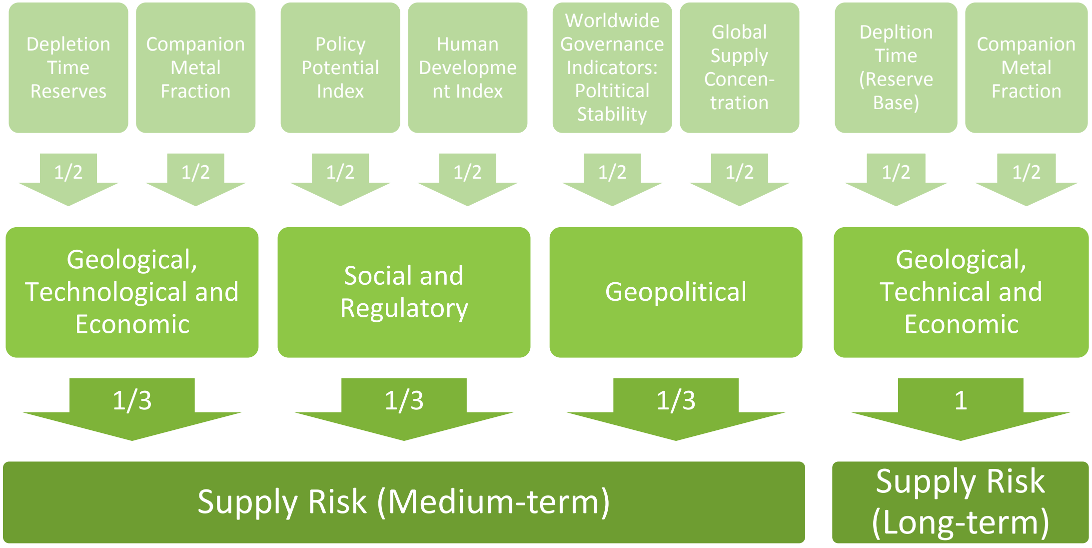
†REE included as a group

In general each of the reports uses at least two dimensions to assess criticality, comparing issues associated with materials supply with concerns associated with demand. In terms of supply the following broad categories may be considered: physical scarcity, production limitations, supply concentration, political risk, and import dependency. Demand issues include importance to economy or sector, demand growth and price fluctuations. A third axis, environmental risk or impact, is also included in some studies as part of criticality assessments to capture environmental concerns. Each of these high level indicators may have “sub-indicators” which contribute to the overall value. Most studies are restricted to a snapshot in time, though some studies use a defined time period that may include forecasts for future materials needs, or vary methodology depending on different timescales considered. This allows for temporal differences in criticality to be assessed. The key features of each of these seven studies are discussed below.

Study 1 - Methodology of Metal Criticality Determination 2011, Graedel et al
This academic paper did not assess any particular metals or technologies but provides an overarching assessment methodology that can apply to studies of metal criticality at the corporate, national or global levels for two different time scales: 5-10 years or longer term (a few decades). The method assessed criticality using three broad categories: supply risk, environmental implications and vulnerability to supply restriction. Different components are used in a flexible way to tailor the study to fit the needs of the particular study, making this arguably the most sophisticated criticality methodology at present.

For supply risk the methodology is based on three components: (1) geological, technological and economic, (2) social and regulatory, and (3) geopolitical (Figure 52). Temporal issues are incorporated by selecting which of these three components is relevant, i.e. for the long term only Stage 1 is employed, while for the medium term all three components are used. Each of these components is further broken down into two indicators, each of which is scored from 0 to 100, with higher values indicating a higher level of risk. For example, in the geological, technological and economic factor one of the indicators is depletion time. The score for this is arrived at quantitatively using mathematical formulae that include variables such as aggregate global geological reserves, aggregate global mining production, the amount that is to be mined at a future time, losses in tailings and future demand.

Figure 52: Methodology for assessing supply risk. Top level indicators are combined to produce components that are in turn used to determine supply risk. For long-term estimates, only one component (geological, technical and economic) is employed.



Another indicator is companion metal fraction. Where the crustal concentration of a metal is less than about 0.1%, it will seldom form usable deposits. In such cases the metal occurs interstitially in the ores of other metals with similar physical and chemical properties. When these low-concentration metals are recovered they are termed “companion metals” and the principal metals in the deposits “host metals’.

The companion metal fraction indicator expresses the potential for supply risk related to the host–companion relationship. The percentage of a target metal that is extracted as a companion is used as the metric for this indicator. A score of 100 therefore represents a metal with all (100%) of its production resulting from mines in which it is mined as a companion metal. For environmental implications, inventory data from the ecoinvent[a] database are used to quantitatively calculate the damage to human health and ecosystems using the ReCiPe[b] and point method.

To quantify vulnerability to supply risk, three different scoping levels are identified: corporate, national and global. For each of these a different methodology is employed. For the corporate level, for example, three components are used to determine supply risk: importance, substitutability and ability to innovate. Each has one or more indicators with different methods of scoring. Together they form a matrix that are then used to calculate vulnerability. Similar methods are used for national and global levels.

Overall this methodology uses a similar approach for supply risk and importance to the EU criticality study, using a series of factors to derive an overall indicator. However, a greater number of factors are considered, reaching a more detailed level for certain aspects. As with the EU study, the methodology is quantitative, but some factors are reliant of expert evaluation for scoring. The environmental indicator is one area that differs significantly from the EU methodology. This measures environmental impacts directly, rather than supply risk associated with risks associated with poor environmental standards.

Study 2 - Critical Metals in Low-Carbon Energy Technologies, EU, 2013

This study analyses the materials demands and potential bottlenecks for implementing the EU's Strategic Energy Technology Plan (SET-Plan). Eleven low-carbon technology areas were included for assessment: hydropower, geothermal energy, marine energy, co-generation or combined heat and power, advanced fossil fuel power generation, fuel cells and hydrogen, electricity storage in the power sector, energy efficiency and CO2 emission reduction in industry, energy efficiency in buildings, road transport efficiency and desalination. This report also included a review and update of a previous study's data, which examined six related technologies: nuclear (fission), solar (photovoltaic and concentrated solar), wind, bioenergy, carbon capture and storage and smart electricity grids.[c]

Both studies broadly employed the same methodology. This more recent work initially considered 60 metallic elements which were screened to the 32 most significant.[d] To achieve this, a bottom-up approach was used, compiling an inventory of all metals used in each technology (Figure 53). The demand for metals associated with the deployment of these technologies was quantitatively evaluated using the scenarios outlined in the SET-Plan or elsewhere.

Further assessment was then conducted on the 32 metals to identify where bottlenecks may impact on the implementation of the technologies. Bottlenecks for these metals were assessed using four criteria falling into two categories to assess an overall risk factor associated with their future supply:

- Market factors:
  - Likelihood of rapid global demand growth for the metal
  - Limitations on expanding production capacity in the short- to medium term.
- Political factors:
  - Supply concentrated from a limited number of countries
  - Political risk of associated with major supplying countries.

---

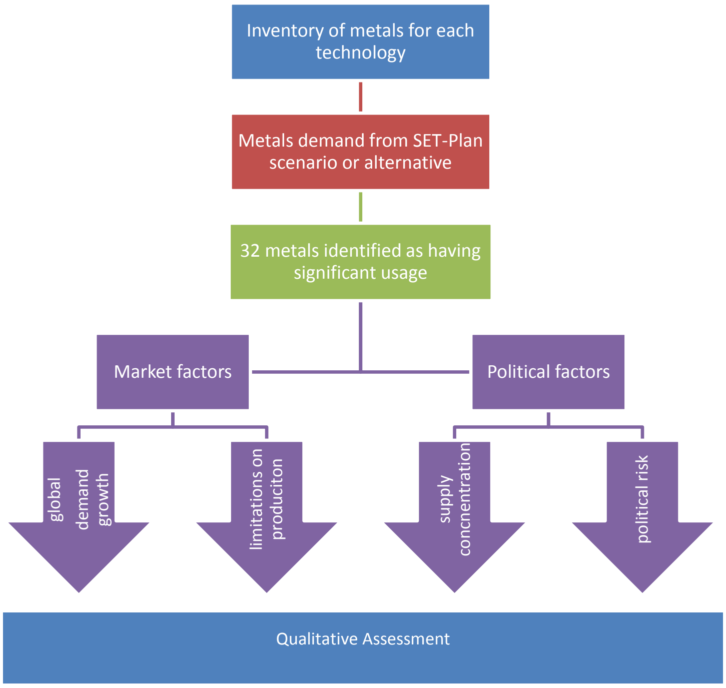
[a] Hischier, R.; Weidema, B.; Althaus, H.-J.; Bauer, C.; Doka, G.; Dones, R.; Frischknecht, R.; Hellweg, S.; Humbert, S.; Jungbluth, N.; Köllner, T.; Loerincik, Y.; Margni, M.; Nemecek, (2010) T. Implementation of Life Cycle Impact Assessment Methods; ecoinvent Report No. 3, version 2.2; Swiss Centre for Life Cycle Inventories: Dübendorf, Switzerland.

[b] Goedkoop, M.; Heijungs, R.; Huijbregts, M.; De Schryver, A.; Struijs, J.; van Zelm, R. ReCiPe 2008. Main Report, Part 1: Characterization, 1st ed.; Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (VROM): The Hague, The Netherlands, 2009.

[c] EU JRC (2011), Assessing metals as Supply Chain Bottlenecks in Priority Energy Technologies

[d] EC JRC (2013) Critical Metals in the Path towards the decarbonisation of the EU Energy Sector

Figure 53: Schematic of methodology for assessing bottleneck materials



This assessment was performed qualitatively, assigning each as “high’, “medium”and “low”considering factors including reserves, production, key applications, processing routes, dominant production countries, price developments, and supply and demand forecasts. These in turn were used to position materials in five different risk categories from high to low. Those metals identified as of high or high-medium risk are shown in Table 37.[a]

This approach differs significantly from the EC critical raw materials methodology, partly due to the need to generate an inventory of materials used for specific technologies, and also in the assessment of risk, which was largely qualitative in this case. A “bottom-up”approach is used, using technology implementation scenarios to estimate materials associated with this implementation. This process is used to screen the metals to provide a short list for further assessment. The next phase is similar to the EU criticality study, using factors such as supply risk and political risk to assess potential for bottleneck. However, due to the forward looking nature of the JRC work the market factors indicator necessarily takes a forward looking view. In addition, this methodology differs in that the values attributed to each factor are judgement based, using background information and expert assessment, rather than being fully quantitative.

Table 37: The metals identified as either of high or high-medium chance of experiencing a bottleneck.

High	High-Medium
REE: Dy, Eu, Tb, Y	Graphite
REE: Pr, Nd	Rhenium
Gallium	Hafnium
Tellurium	Germanium
	Platinum
	Indium

Source: EU JRC Presentation

---

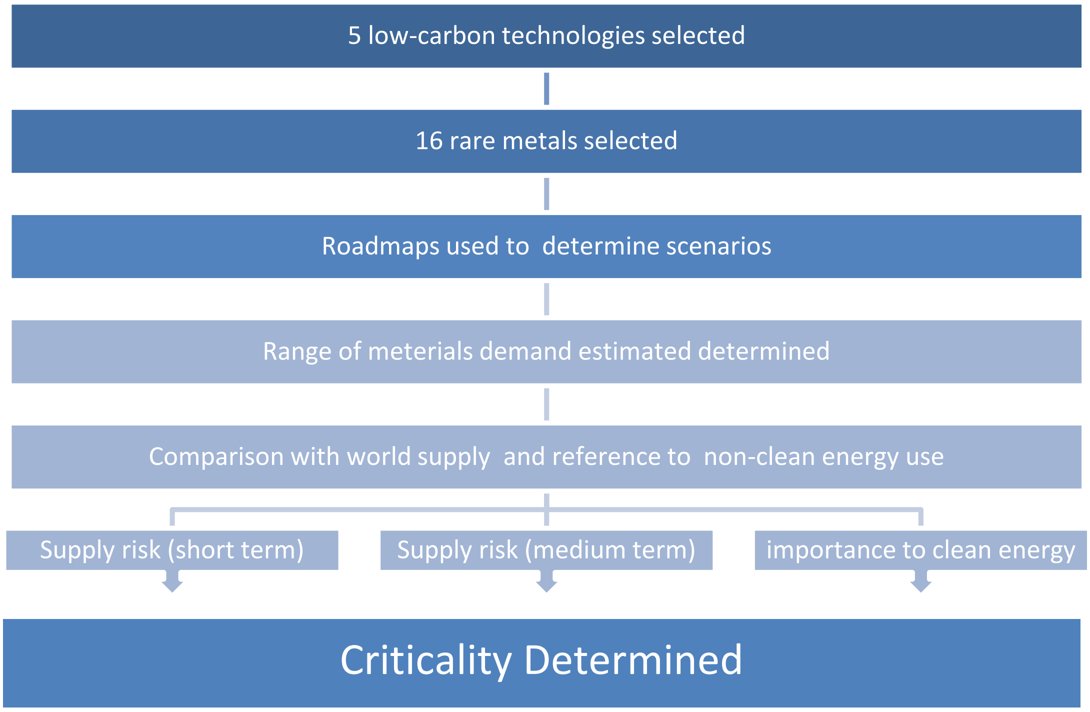
[a] EC JRC (2013), Critical Metals in the Path towards the decarbonisation of the EU Energy Sector

Study 3 - Critical Materials Strategy, USA, 2011

This report addresses the short- and medium-term materials supply risks for the deployment of wind turbines, EVs, solar cells, and energy-efficient lighting (Figure 54).

Sixteen “rare”metals were considered for assessment and supply challenges (Table 38). In the short term (present-2015) five rare earth metals (dysprosium, neodymium, terbium, europium and yttrium) were identified as critical. Other elements, cerium, indium, lanthanum and tellurium, were found to be near-critical. International scenarios and roadmaps are used to determine materials demand, with some attention given to the US specifically. These future scenarios are used to develop a range of estimates for the material consumption for each of the key materials to 2025. These are compared to forecasts of world supply and with reference to non-clean energy uses.

Figure 54: Criticality assessment methodology employed by Critical Materials Strategy, USA, 2011



The study then assesses the criticality of the key materials using two criteria: importance to clean energy and supply risk for both the short term, to 2015, and for the medium term, to 2025. These criteria are in turn determined by the weighting of individual factor scores:

- Importance to clean energy: clean energy demand (75%) and substitutability limitations (25%)
- Supply risk: basic availability (40%), competing technology demand (10%), political, regulatory and social factors (20%), co-dependence with other markets (10%), and producer diversity (20%).

Each individual factor was given a score (out of 4) which was determined qualitatively and weighted to give the scores for the two criteria. A material was considered critical if it had a score of a least 3 for both criteria and near critical if it had a score of a least 3 on one criterion with a score of 2 for the other criterion.

This study shares parallels with the JRC bottleneck materials study (Study 2), both in scope and approach, using a bottom-up approach for a specific group of technologies. However, in this case the materials of interest are pre-determined here through expert opinion rather than using a screening exercise. One significant difference is that this study took into account changes in risk over time taken. This is achieved by using different supply risk considerations in this assessment, therefore short and longer term criticality has been differentiated for different metals.

Table 38: Metals selected for assessment and those found to be critical or near critical in the short term by US DoE

Sixteen metals selected for Assessment		Metals critical in short term (present – 2015)	Metals near critical in short term (present - 2015)
Cerium	Manganese	Dysprosium	Cerium
Cobalt	Neodymium	Europium	Indium
Dysprosium	Nickel	Neodymium	Lanthanum
Europium	Praseodymium	Terbium	Tellurium
Gallium	Samarium	Yttrium	
Indium	Tellurium		
Lanthanum	Terbium		
Lithium	Yttrium		

Source: US DoE

Study 4 - Critical metals for future sustainable technologies and their recycling potential, UNEP, 2010
This study focused on materials required for future sustainable technologies. Four major technology clusters were selected: electrical and electronic equipment (EEE), PV technologies, battery technologies and catalysts. Eleven minor metals were selected for analysis, each with use in at least one technology cluster: cobalt, gallium, germanium, indium, lithium, palladium, platinum, rare earths, ruthenium, tantalum and tellurium.

The metals were assessed using three indicators: demand growth, supply risks and recycling restrictions. Each of these was calculated based on data and information collected on the metals. The indicators had a number of factors which contributed the assessment:

- **Demand growth:** This was designated as rapid if world demand was expected to increase by more than 50% between 2007 and 2020, i.e. an implied average compound annual growth rate (CAGR) of 3.2%. If world demand was expected to increase by more than 20% between 2007 and 2020, i.e. an implied average CAGR of 1.4%, demand growth was scored as moderate.
- **Supply risks:** This was assessed by the interaction of regional concentration of mining (scored as high if over 90% of global production was in three countries), physical scarcities (reserves compared to annual demand), temporary scarcities (time lag between production and demand) and structural or technical scarcity (whether metal was a minor or by-product).
- **Recycling restrictions:** These were assessed by considering the scale of use of dissipative applications, physical/chemical limitations for recycling, lack of suitable recycling technologies or infrastructure and the lack of price incentives for recycling.

The metals were prioritised by interpreting this analysis and assessing it against a timeline for urgency. In the short term tellurium, indium and gallium were identified as most critical, Table 39.

Table 39: Criticality of metals from short term to long term for UNEP study

Short term (within next 5 years)	Mid-term (till 2020)	Long-term (till 2050)
Tellurium	Rare earths	Germanium
Indium	Lithium	Cobalt
Gallium	Tantalum	
	Palladium	
	Platinum	
	Ruthenium	

Source: UNEP

As with Study 2 and Study 3 this study used a bottom up approach, focusing on a specific set of technologies linked to sustainability. It is different from the former studies in that three main factors were used to assess criticality, with recycling restrictions included as a top level indicator. Other studies have considered this within the supply risk category. This assessment also differed from the other studies in that it took a semi-quantitative approach, with some indicators based on measurable values at the level of the criticality assessment. However, these were then fed into of a high/medium/low assignment, similar to that seen in the previous studies.

Study 5 - Plans for Stable Procurement of Rare Metals, South Korea, 2010
The purpose of this study was to identify rare metals of importance to South Korea, to allow supplies to be secured in the long term. This was a result over concerns due to South Korea's limited natural resources, small mineral supporting industry, and poor recycling rates.

An initial list of 56 "rare"elements was identified, all of which are of importance to the Korean economy and were chosen due to instability of supply and price fluctuations. The full list of these elements is not available; however, it is thought to include the following: antimony, boron, bismuth, cadmium, cobalt, chromium, gallium, germanium, indium, lithium, magnesium, manganese, molybdenum, niobium, nickel, PGMs (6 elements), REEs (17 elements), selenium, silicon, tantalum, titanium, tungsten, vanadium and zirconium.

In addition to the initial factors of instability of supply and price fluctuations, two further factors were assessed. The first relates to geology, comprising the resource rarity and the geological distribution (i.e. whether the minerals are present in mineable concentrations). The method for assessing rarity was to compare each metal's crustal abundance relative to that of iron to provide some insight into abundance. The second factor relates to market demand, specifically the level of domestic demand in Korean industry for each metal and the forecast rate of growth. The instability of supply is determined by the concentration of supply and is higher for elements whose production is concentrated in a few countries.

Out of the initial list, 11 elements (or groups of elements) were designated as strategic critical elements. These were: indium, gallium, rare earth elements, silicon, magnesium, titanium, tungsten, platinum group metals, nickel, lithium and zirconium.

This study shares a similar scope to the EC study, i.e. an assessment of materials critical to a particular territory. Some factors to consider are shared, for instance a measure of importance to the economy, and concentration of supply. However, other factors were also considered such as price volatility and an assessment of geological availability of the metal through a more sophisticated technique than reserves. It is unclear how these individual measures are brought together to form an overall assessment of criticality.

Study 6 - Research Priorities for More Efficient Use of Critical Materials from a U.S. Corporate Perspective, General Electric, 2010
This study identified which of the materials that GE uses were most at risk of supply constraints or price increases.

It was not practical to review the risks of every element used by GE, due to the broad range of materials used. Instead the top 24 elements in terms of annual purchase value within GE were identified. From this list, 11 (minor metal) elements were selected for detailed risk analysis, on the basis that these non-commodity elements can have significant price deviations due to constrained supply. GE's methodology in assessing materials risks is similar to other studies that use dimensions to identify critical materials. In this case the impacts of restriction on GE and supply and price risk were used. Both of these have a number of sub-risks, each of which is rated with a score of between 1 (very low) and 5 (very high). These sub-risks are then averaged to determine an overall score for that axis. The sub-risks are:

- **Impact of restriction on GE:** GE % of world supply, impact on GE revenue, GE ability to substitute and ability to pass through cost increases
- **Supply and price risk:** abundance in the earth's crust, sourcing and geopolitical risk, co-production risk, demand risk (growth), historic price volatility (last five years only) and market substitutability.

Of the 11 elements selected for the risk analysis, seven were designated as being critical and identified for further development planning. The most critical element identified was rhenium, used for superalloys, primarily in GE's high efficiency turbine engines. REEs and tellurium are also among those thought to have been identified as being critical; however, GE regards the results as being proprietary and the full list is not available for review within this report, nor is the precise methodology.

Whilst the results and some of the methodology is unclear, these impact and risk measures take into account many of the factors which the EU study uses, but in a way that is appropriate for GE. Additional factors such as % of world supply for GE, co-production risk and price volatility are also included.

Study 7 - Raw materials for emerging technologies, Germany, 2009

The purpose of this study was to examine the dependence on certain raw materials of a group of pilot and development stage technologies. Within this study 32 separate emerging technologies were included for detailed analysis (Figure 55).

Figure 55: Outline of methodology used to determine criticality

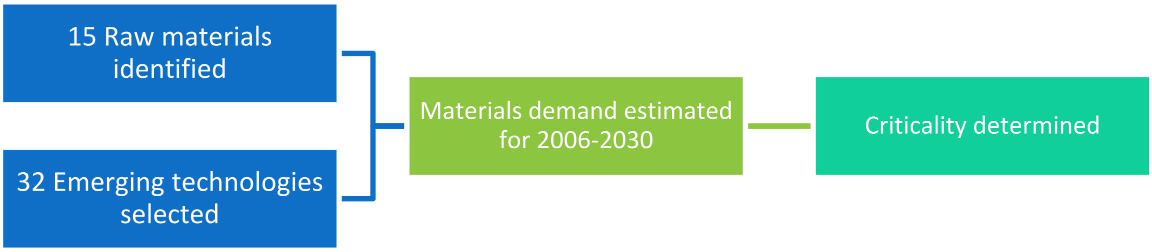


Table 40: Supply of materials for emerging technologies expressed as a ratio of 2006 supply.

Metal	Uses	2006	2030
Gallium	Thin layer PVs, IC, LED	0.18	3.97
Indium	Displays, thin layer PVs	0.40	3.29
Scandium	Fuel cell, aluminium alloying element	0	2.31
Germanium	Fibre optic cable, IR optical technologies	0.28	2.20
Neodymium	Permanent magnets, laser technology	0.23	1.66
Platinum	Fuel cells, catalysts	0	1.35
Tantalum	Micro capacitors, medical technology	0.40	1.02
Silver	RFID, lead-free soft solder	0.28	0.83
Tin	Lead-free soft solder, transparent electrodes	0.62	0.77
Cobalt	Lithium-ion batteries, synthetic fuels	0.21	0.43
Palladium	Catalysts, seawater desalination	0.09	0.29
Titanium	Seawater desalination, implants	0.08	0.29
Copper	Efficient electric motors, RFID	0.09	0.24
Selenium	Thin layer PVs, alloying element	Low	0.11
Niobium	Micro capacitors, ferroalloys	0.01	0.03
Ruthenium	Dye-sensitized solar cells, titanium-alloying element	0	0.03
Yttrium	Super conduction, laser technology	low	0.01
Chromium	Seawater desalination, marine technologies	<0.01	<0.01
Antimony	ATO, micro capacitors	<0.01	<0.01

Source: Fraunhofer and IZT

15 metals was included for analysis (Table 40), selected due to their importance to the German economy and the concentration of the supply in politically unstable countries, as well as their importance in the

emerging technologies. The selection of technologies was made to contain all of the high-tech and cutting-edge technology sectors. The approach taken is “bottom-up”; the technology’s specific properties, progress to state-of-the art, the specific functions provided by the raw materials, the possible application spectrum and the potential markets are all considered. A factor-based approach is employed, which assesses the material demand as the combination of material demand per unit multiplied by the number of units per annum (both of these factors vary over time). These insights are put within a framework of conditions, such as world economic development and projections of future technology use, to derive world demand for the raw materials for a base year of 2006 and a time horizon of 2030. Seven materials were found to have a demand in 2030 greater than current world supply. These are shown in Table 40 where the demand is expressed as a ratio of 2006 supply. This analysis reveals how raw material demand is driven by the development of new technologies and shows that certain technologies will produce supply risks.

Summary and comparison with EU Methodology

The criticality study conducted by the European Commission is amongst the most high profile and widely cited. Other equivalent studies have been performed, e.g. by the United States, the South Korean government, General Electric and for specific sectors such as defence or clean technology. Understandably the aims, scope and methodology of these studies varies significantly, depending on factors such as their purpose and audience.

Perhaps the clearest difference between these studies is the overall methodological approach taken, with many using a bottom-up approach due to their focus on a specific technology. However, this methodology is less appropriate for the EU study given its purpose and scope, and the existing approach of using the materials as the starting point remains the most suitable.

A comparison of materials identified as critical within these studies can be made with the 2010 EU list , Table 41 below. Many, materials overlap, particularly those associated with hi-tech uses such as gallium, indium, PGMs and REEs. However, many are unique to the EU study, this is partly due to the scope of the work which includes industrial minerals and also due to the context in which criticality is assessed.

Table 41: Comparison of materials identified as critical in the studies analysed.

	Material	Study 2	Study 3	Study 4	Study 5	Study 6[1]	Study 7	EU CRMs 2010	EU CRMs 2013
	Antimony							X	X
	Beryllium							X	X
	Borates								X
	Chromium								X
	Cobalt			X				X	X
	Coking Coal								X
	Fluorspar							X	X
	Gallium	X		X	X		X	X	X
	Germanium	X		X			X	X	X
	Graphite (Nat.)	X						X	X
	Hafnium	X							
	Indium	X	X	X	X		X	X	X
	Lithium			X	X				X
	Magnesite								X
	Magnesium				X			X	X
	Nickel				X				
	Niobium							X	X
	Phosphate rock								X
PGMs	Palladium			X	X			X	X
	Platinum	X		X			X		
	Ruthenium			X					
	Other PGMs								
	Rhenium	X				X			
REEs	Cerium		X	X	X	X		X	X
	Dysprosium	X	X						
	Europium	X	X						
	Lanthanum		X						
	Neodymium	X	X				X		
	Praseodymium	X							
	Scandium						X		
	Terbium	X	X						
	Yttrium	X	X						
	Other REEs								
	Silicon Metal				X				X
	Tantalum			X			X	X	
	Tellurium	X	X	X		X			
	Titanium				X				
	Tungsten				X			X	X
	Zirconium				X				

[1] *The full list of critical materials (7) is not available as the results of this report are regarded as being proprietary.*

Annex G – Land Use and Mining Governance Data (EITI & PPI)

Deposit Categorisation

ProMine Database – Status of deposits and aggregated parent category for mapping

STATUS	Parent Category
Abandoned industrial mining district	not operating
Aeromagnetic anomaly	anomaly
Alluvial anomaly	anomaly
Conductivity, resistivity	anomaly
Deposit of unknown status	unknown
Deposit or prospect of unknown status	unknown
Deposit under development - project	under development
DEPOSITS	unknown
DEPOSITS - PROSPECTS	unknown
Dormant deposit	not operating
Dormant district	not operating
Electrical anomaly	anomaly
Eluvial anomaly	anomaly
Geochemical anomaly	anomaly
Geophysical ground anomaly	anomaly
Gravimetrical anomaly	anomaly
Group of mineral occcurrences	unknown
Group of stream-sediment anomalies	anomaly
Induced polarization (IP)	unknown
Industrial project under development	under development
Intermittent industrial mine	operating
Intermittent mine	operating
Intermittent mine	operating
Isolated mineral occurrence	unknown
Isolated soil anomaly	anomaly
Magnetic anomaly	anomaly
Mineral occurrence	unknown
Old exploration workings	not operating
Old industrial mine, abandoned deposit	not operating
Old industrial mine, exhausted deposit	not operating
Old mine workings	not operating
Old mining district	not operating
Old prospect	not operating
Old small-scale mine, abandoned deposit	not operating
Old small-scale mine, exhausted deposit	not operating
Old workings	not operating

STATUS	Parent Category
Primary occurrence of unknown status	unknown
PRIMARY OCCURRENCES	unknown
Producing deposit	operating
Producing district	operating
Producing industrial mine	operating
Producing province	operating
Producing province or district	operating
Producing small-scale mine	operating
Prospect	unknown
Prospect under (downstream) evaluation	under development
Prospect under (upstream) reconnaissance	under development
PROVINCE- DISTRICT	unknown
Remote sensing and radar anomaly	anomaly
Self polarization (SP)	unknown
Small-scale project under development	under development
Subeconomic deposit	not operating
Texture, structure anomaly	anomaly
Unexploited deposit	not operating
UNKNOWN STATUS	unknown

EITI Status of Countries

Mining reporting included (as of July 2013)

Country	Status (July 2013)
Afghanistan	Candidate
Albania	Compliant
Australia	In progress
Azerbaijan	Compliant
Burkina Faso	Compliant
Cameroon	Candidate
Canada	In progress
Central African Republic	Lost or suspended
Chad	Candidate
Colombia	In progress
Côte d'Ivoire	Compliant
Democratic Republic of the Congo	Lost or suspended
Ethiopia	In progress
France	In progress
Gabon	Lost or suspended
Germany	In progress
Ghana	Compliant
Guatemala	Candidate
Guinea	Candidate
Honduras	Candidate
Indonesia	Candidate
Italy	In progress
Kazakhstan	Candidate
Kyrgyzstan	Compliant
Liberia	Compliant
Madagascar	Lost or suspended
Mali	Compliant

Country	Status (July 2013)
Mauritania	Compliant
Mongolia	Compliant
Mozambique	Compliant
Myanmar	In progress
Niger	Compliant
Peru	Compliant
Philippines	Candidate
Sierra Leone	Lost or suspended
Solomon Islands	Candidate
Tajikistan	Candidate
Tanzania	Compliant
Togo	Compliant
Ukraine	In progress
United Kingdom	In progress
United States	In progress
Zambia	Compliant

No mining reporting

Country	Status (July 2013)
Equatorial Guinea	Lost or suspended
Iraq	Compliant
Nigeria	Compliant
Norway	Compliant
Republic of the Congo	Compliant
East Timor	Compliant
Yemen	Lost or suspended
São Tomé and Príncipe	Candidate

PPI Scores (2012/2013)

Country	PPI	Rank
Finland	95.5	1
Sweden	93.6	2
Ireland	89.7	3
Norway	82.4	4
Greenland	79.9	5
Botswana	78.1	6
Canada	77.4	7
Chile	67.7	8
Australia	66.1	9
United States	65.8	10
Morocco	65.6	11
New Zealand	65.1	12
French Guiana	64.6	13
Namibia	63.7	14
Mauritania	61.6	15
Mexico	57.3	16
Spain	54.6	17
Bulgaria	53.6	18
Serbia	49.9	19
Turkey	49.7	20
Ghana	48.2	21
Burkina Faso	46.0	22
Argentina	44.3	23
Poland	42.7	24
Peru	42.0	25
Zambia	41.7	26
Dominican Republic	39.7	27
Brazil	38.2	28
Panama	35.8	29

Country	PPI	Rank
South Africa	35.0	30
Colombia	34.4	31
Guyana	32.9	32
Egypt	32.4	33
Niger	32.2	34
Suriname	31.0	35
China	28.5	36
Russia	28.1	37
Tanzania	28.0	38
Guinea	26.4	39
Papua New Guinea	26.1	40
Mali	24.9	41
Kazakhstan	23.3	42
India	21.1	43
Ecuador	19.0	44
Honduras	17.9	45
Mongolia	17.9	46
Madagascar	16.5	47
Romania	16.2	48
Greece	15.6	49
Philippines	14.0	50
Guatemala	13.8	51
Bolivia	13.8	52
Zimbabwe	13.4	53
Kyrgyzstan	13.4	54
Democratic Republic of the Congo	12.3	55
Venezuela	11.8	56
Vietnam	11.6	57
Indonesia	9.4	58

NB: Scores for Argentina, Australia, Canada and the United States are averaged from local regions.

Annex H – Possible Changes to Scope and Quantitative Methodology

In this report, the assessment of raw materials was carried out using the same quantitative methodology used in the original 2010 exercise[a], with the addition of several materials. This was done chiefly in the interest of comparability. Influences on criticality are discussed in Section 5; however, an important further aspect of the work leading to this report was to propose different ways of improving the methodology taking into account stakeholder feedback received since 2010. Three sets of changes are proposed below, relating to different aspects of this work: scope, adjustments of the existing methodology, and additional quantitative indicators.

Scope

The scope of this study has been discussed numerous times over the course of this study and in feedback from the previous study, consequently an update may be appropriate for the next revision. Several additional abiotic materials may be considered for inclusion as candidate materials for analysis, for example arsenic, bismuth, cadmium, iodine, lead, and zirconium. Other non-energy raw materials important as chemical precursors might also be considered, though this would represent a significant change in the scope of materials assessed. Biotic materials also require consideration. As outlined in Section 6.6 the study could also include further biotic materials, or this analysis could be performed in a separate for study for biotic materials, depending on the requirements of the Commission.

Adjustments of the existing methodology

Thresholds

One point of critique on the current methodology is the setting of the thresholds separating the “critical” from the “non-critical” regions in the two-dimensional graph used to compare the relative ranking of the raw materials. The location of these thresholds is certainly a matter of decision not of derivation; it was a judgement made by the original Ad-hoc Working Group for the distribution of points in 2010 which has been kept unchanged in the current exercise. The location of the thresholds may be challenged on three accounts:

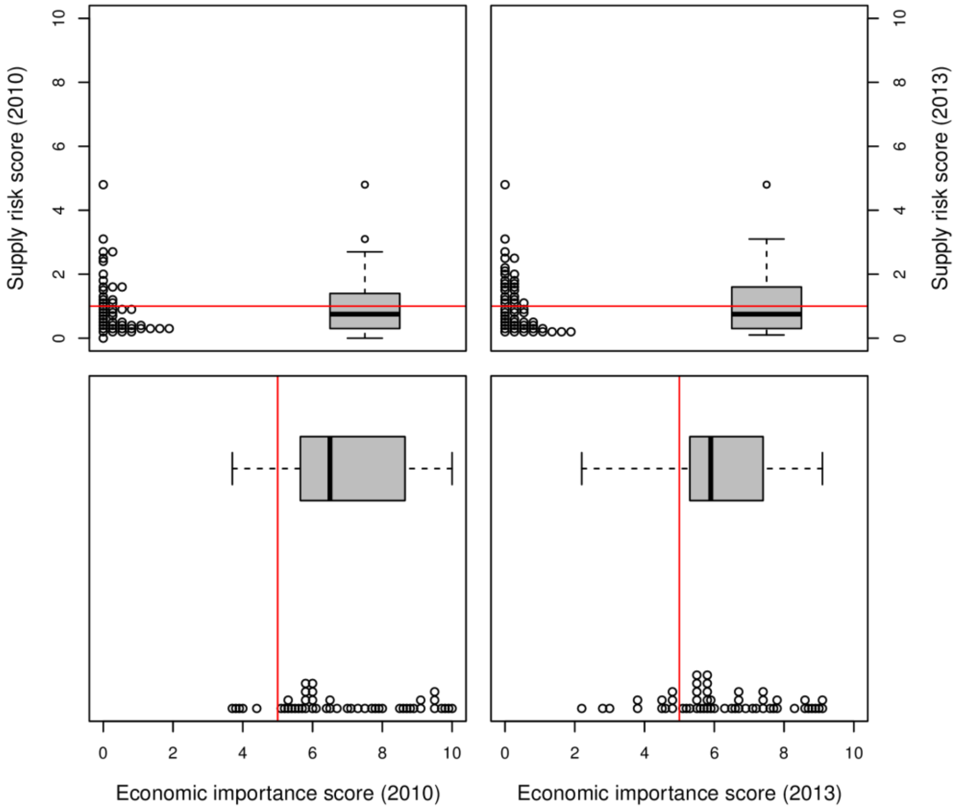
1. That they are sharp thresholds and small changes in a score can lead to a raw material being considered critical or not. This is discussed in part in the next section.
2. That they are unequally strict for supply risk and economic importance: while less than 50% of supply risk scores lie above the set threshold, more than 75% of the scores for economic importance lie above the respective threshold (Figure 56). This *partly* reduces the criticality exercise to a relative ranking on supply risk, whereby only one raw material (baryte) was excluded on account of economic importance in 2010 and three (baryte, scandium, rhenium) in 2013.
3. That the thresholds do not react to changes in the relative locations of the points although the exercise is a relative one.

One possibility of addressing Points 2 and 3 would be to define the thresholds for economic importance and supply risk in terms of the distribution of points (i.e. a certain percentile) (Figure 56). This would automatically address Issue 3 because the thresholds would change according to the relative locations of dots for every update of the list. Regarding Issue 2, it is clear that the location of the thresholds is a matter of decision, expressed either as an absolute value of a score or a certain value of a percentile. The relative positioning of the thresholds appears logical for a primarily resource consuming economic area such as the European Union, where security of supply is a pressing issue.

---

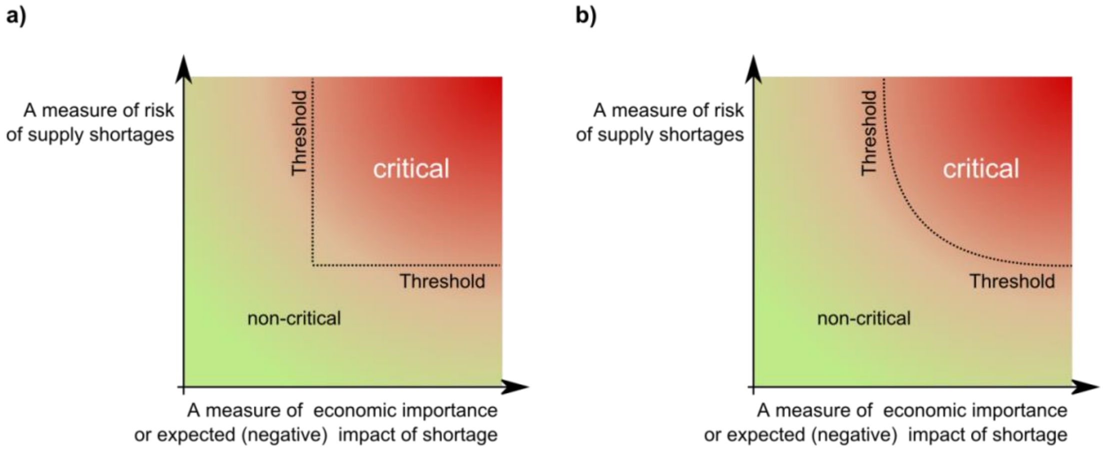
[a] Ad-hoc Working Group on defining critical raw materials (2010): Critical raw materials for the EU. Edited by European Commission.

Figure 56: Distribution of supply risk and economic importance scores in 2010 and 2013. The dots are placed at the location of individual raw materials (one dot = one raw material) and stacked if they have the same score (rounded to 0.1). The box plots characterise the distributions of points: the thick black line in the centre marks the location of the median, 50% of the dots are contained within the gray box, and essentially all points are located within the bounds of the box plot (excluding outliers).



Aside from the location of the thresholds, the shape of the "critical" region may be considered (and changed) without affecting the background data. Currently, this is a square section[a] but alternative shapes may be considered (Figure 57).

Figure 57: Current (a) and possible alternative (b) of defining the "critical" region based on the same numerical thresholds.



---

[a] Work published by the U.S. Department of Energy (2010, 2011) also uses a square section to define the "critical" region.

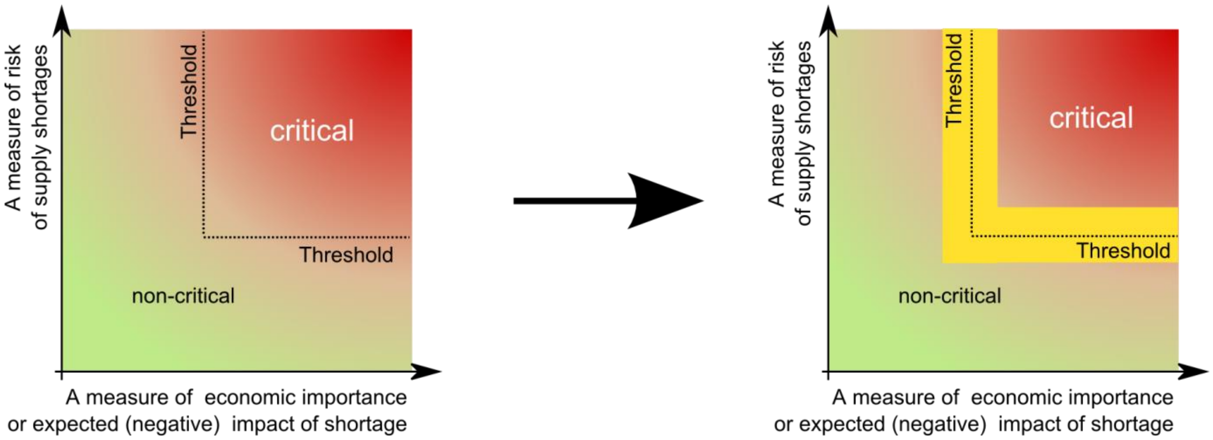
While it is also possible to create more nuanced ad-hoc differentiations[a], the recurring nature of the EU criticality exercise dictates a more stable approach. A curved section such as that shown in Figure 57b can be defined in such a way that it remains stable across iterations of the criticality exercise by tying it to the values of the thresholds[b]. Moreover, the use of a curved section (however defined) better emphasizes the proximity of the points to the maximum score in both dimensions than the square area. However, the square area has the benefit of both simplicity and transparency.

Degrees of criticality and transition zone

All criticality exercises are a relative ranking in at least one dimension using a variety of indicators. In this ranking, the "degree of criticality" of a raw material can vary from absolutely non-critical to extremely critical[cde]. There is no need to set thresholds in academic exercises dealing with how to rank the selected raw materials. However, as a policy instrument, a list of critical raw materials needs to be clear and thus, thresholds must be set in some way. Some shortcomings of thresholds regarding their location were addressed in the previous section. Here, the sharpness of the thresholds is examined.

That the selected thresholds are sharp (i.e. a material is considered critical as long as both scores for economic importance and supply risk are greater or equal to the respective numerical thresholds) can be challenged because raw materials can be distinctly classified as "critical" or "non-critical" despite very similar scores. As a result, comparatively small changes in the scores can make a raw material move into or out of the "critical" region.

Figure 58: Introducing a "transition zone" between "critical" and "non-critical" regions.



Although it is desirable for the methodology to be sensitive to changing circumstances, a certain degree of variation is to be expected year-to-year that does not reflect fundamental changes in supply or demand of a raw material and thus should not necessarily result in a change of classification. Moreover, there are uncertainties related to the location of the points that are ignored by the sharp placement of both points and thresholds. Therefore, the establishment of a "transition zone" (or buffer zone) between the "critical" and "non-critical" regions appears warranted[f] (Figure 58). This transition zone needs to

---

[a] Erdmann, L.; Behrendt, Siegfried; Feil, Moira (2011): Kritische Rohstoffe für Deutschland. Identifikation aus Sicht deutscher Unternehmen wirtschaftlich bedeutsamer mineralischer Rohstoffe, deren Versorgungslage sich mittel- bis langfristig als kritisch erweisen könnte. Edited by KfW Bankengruppe. Berlin.

[b] This holds true whether the thresholds are numerically fixed or defined in terms of the distribution of points.

[c] Erdmann, Lorenz; Graedel, Thomas E. (2011): Criticality of Non-Fuel Minerals: A Review of Major Approaches and Analyses. In Environ. Sci. Technol. 45 (18), pp. 7620–7630

[d] Graedel, T. E.; Barr, Rachel; Chandler, Chelsea; Chase, Thomas; Choi, Joanne; Christoffersen, Lee et al. (2012): Methodology of Metal Criticality Determination. In Environ. Sci. Technol. 46 (2), pp. 1063–1070

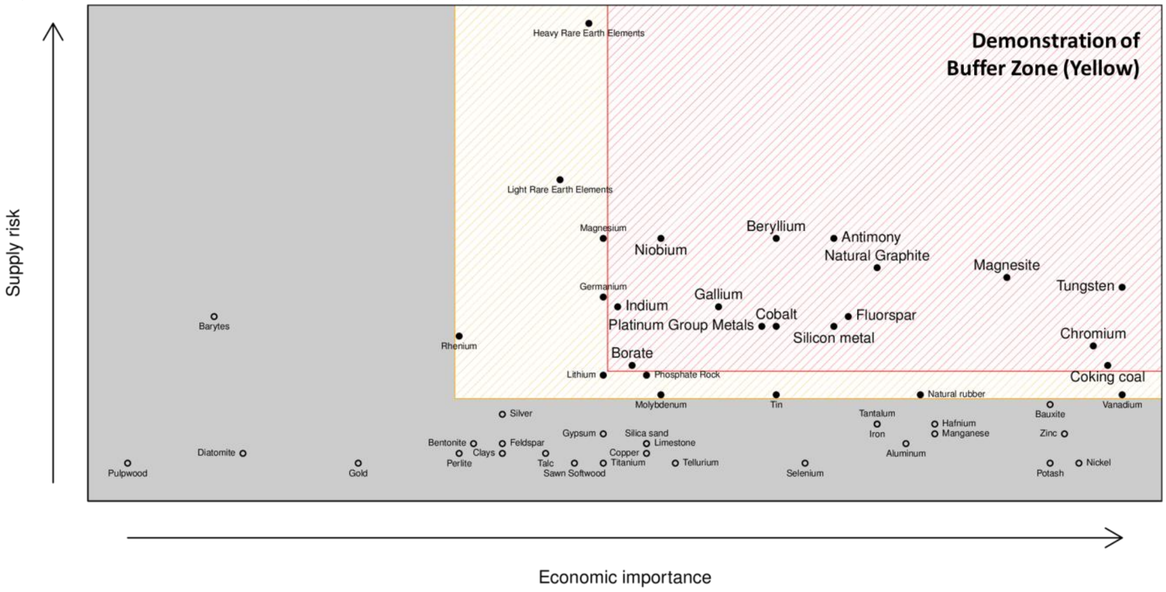
[e] Buijs, Bram; Sievers, Henrike; Tercero Espinoza, Luis A. (2012): Limits to the critical raw materials approach. In Proceedings of the ICE - Waste and Resource Management 165 (4), pp. 201–208

[f] See e.g. U.S. Department of Energy (2011): Critical Materials Strategy

receive a suitable name[a] such that materials falling within this region may be properly referred to and considered in policy documents (e.g. "near-critical", "of concern"). It is proposed that this three-tiered classification is clear and simple enough to draw attention to the issues surrounding raw materials supply and for policy making.

Like the definition of thresholds themselves, the definition of the transition zone is a matter of decision. A very simple approach would be to define the width of the transition zone in terms of the location of the thresholds (i.e. threshold value plus/minus a certain % or absolute value). Given that the current numerical threshold for supply risk is 1 and that the scores are rounded to the nearest 0.1, the minimum range of a transition region for supply risk would be 1 ± 0.1 (equivalent to threshold ± 10%). Transplanting this relation to the economic importance axis would lead to 5 ± 0.5. This is demonstrated on the results for this study in Figure 59.

Figure 59: Demonstration of criticality buffer zone (in yellow)



The introduction of a transition zone as defined above (threshold ± 10%, square "critical" region defined as greater than—as opposed to greater or equal to—the respective thresholds) would enclose the light and heavy rare earth elements (not the heavy rare earth elements): magnesium, germanium, lithium, phosphate rock, rhenium, molybdenum, natural rubber, tin, and vanadium. Of these, the first six are considered critical and the last five non-critical following the analysis presented in this report with the current methodology. It is possible to create an equivalent transition zone for a curved "critical" region. The results would depend on the exact definition of the curve and are necessarily less transparent in the sense that they would be more difficult to verify by third parties.

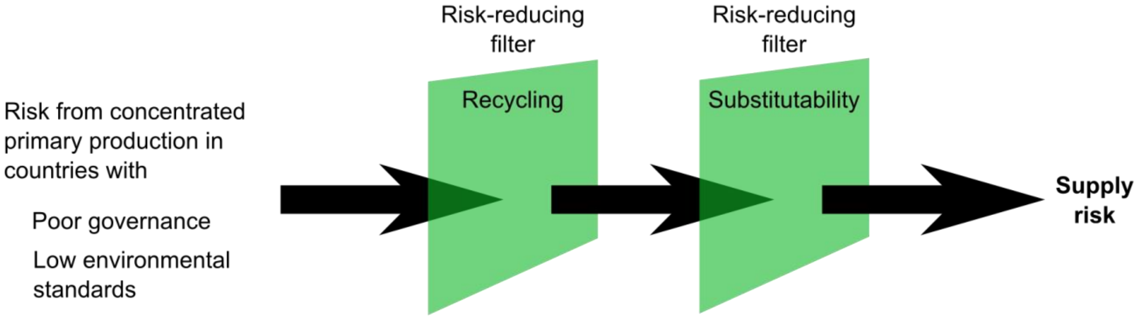
The influence of substitutability on the numerical scores

The current methodology for assessing supply risk strongly emphasizes the role of substitutability (Figure 59) following the intention of the original communication on the raw materials initiative. A histogram of the weighted substitutability scores used in this exercise is shown in Figure 60 (left). However, as acknowledged in the original report, the values of substitutability index used are necessarily estimates based on expert opinion as opposed to being (more or less) verifiable data (cf. production figures, market figures). Thus, the use of these values can and has been challenged as unduly changing the supply risk score.

---

[a] Raw materials falling close (but just below) the threshold for supply risk were expressly highlighted in the 2010 report but no name was suggested following the clear classification of "critical" vs. "non-critical".

Figure 60: Visualization of the supply risk assessment.



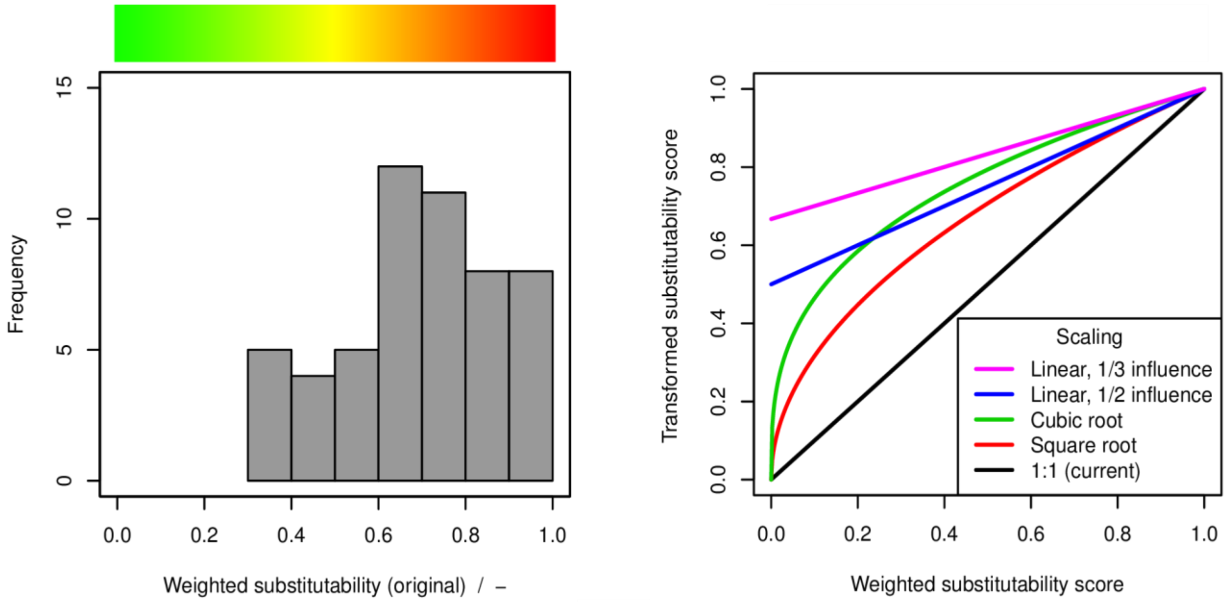
Considering that substitutability is broadly acknowledged as an important factor in determining the criticality of a raw material and that the assessment of substitutability scores is done for each application (instead of for a raw material), it appears reasonable to continue to include substitutability in the quantitative methodology. However, it does not appear necessary to keep the same weighting.

Figure 60 (right) shows some possibilities of rescaling the substitutability scores to reduce their impact on the assessment of supply risk:

- Linear scaling to reduce the impact of the substitutability assessment to either one half or one third of current impact.
- Curved scaling using square and cubic roots of the substitutability scores. Of course other curves are possible.

Notice that the linear (one half influence) and square root rescaling are very similar for high values of the substitutability score but the linear rescaling changes the impact more strongly than the square root function. The same applies to the comparison of the linear (one third influence) with the cubic root rescaling. While the shape of the rescaling (magnitude of the correction) function is a matter of decision, the use of a linear function appears more intuitive.

Figure 61: (left) Histogram of the weighted substitutability scores used in the current exercise. (right) Different possibilities of scaling the substitutability scores to reduce their impact on the assessment of supply risk.

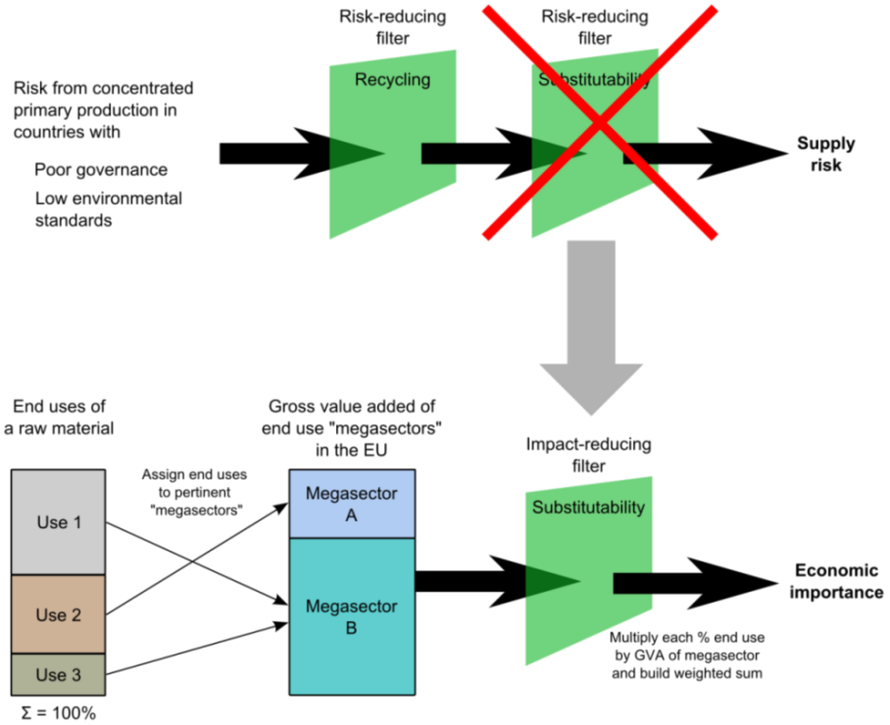


Rescaling the substitutability score to reduce its impact on the assessment of supply risk would have the effect of increasing the supply risk scores of most raw materials considered in the analysis. Therefore, the thresholds would likely need to be redefined although the methodology as visualized in Figure 59 would not have to be changed. A positive side benefit of rescaling would be the reduction of the impact that uncertainties in the substitutability score have on the supply risk score.

Substitutability as an impact reducing factor

In the current methodology, the possibility to substitute one raw material for another (not subject to the same supply risks) or by an alternative technology is considered as a risk-reducing factor (Figure 60). However, it has been pointed out that the effect of substitution is not so much to reduce the risk of supply disruptions but rather to ameliorate or even cancel the impact of a given supply restriction. This critique appears reasonable and implies that substitutability should be included in the assessment of economic importance and removed from the assessment of supply risk (Figure 62). Note that the adoption of this change implies a redefinition of the thresholds for both economic importance and supply risk.

Figure 62: Visualization of the proposed change in the equations for estimating supply risk and economic importance. Notice that the data needs remain the same.



Weighting of EPI indicators

The EPI ranking is annually published by Yale University and ranks countries on performance indicators across policy categories that cover both environmental health and ecosystem vitality provide a gauge at a national government scale of how close countries are to established environmental policy goals. The index is measured using twenty two indicators across ten policy categories ranging from air pollution, to biodiversity & habitat, to water.[a] Within the existing study the overall EPI score is used, which includes several indicators which are potentially less relevant to the raw materials sector, such as fish stocks overexploitation. Therefore there may be scope to weight or omit certain indicators in the EPI, using a

---

[a] http://epi.yale.edu/sites/default/files/downloads/Appendix1%2012.20.12.pdf

modified version in the calculation of supply risk due to low environmental standards which is more appropriate to for the raw materials industry.

Sources of data

Several sources of data were highlighted for possible use in the next study. These include but are not limited to the outputs of the Minventory project (stocks for recycling), Raw Materials Intelligence (recycling rates), resource efficiency data and indicators and EU recycling rates where available.

Additional quantitative indicators

Company concentration

Company concentration was discussed in Section 5.3.2, reviewing its influence on material supply. Concerns over cartel like behavior amongst countries were also raised, and was proposed as a possible factor to consider in future work. If either of these is desired to be included in a future refinement of methodology a quantitative approach is required.   Several options are possible.

A combination of country and company concentration into a single measure is a first possibility. A natural way to do this would be to use the Herfindahl-Hirschmann-Index (HHI) as this is commonly used for company concentration in merger analysis and is already been in use for concentration at the country level. Therefore the corresponding equation for supply risk can be expanded including both company concentration and concentration at the country level. The current supply risk formula is depicted in Equation 7, with the concentration at country level weighted with the political risk expressed in the world governance indicator (WGI, this term is marked in gray).

Equation 7: Current supply risk formula

$$SR_i = \sigma i \quad \cdot (1 - \rho_i) \sum_c (s_{ic})^2 \cdot WGI_{ic}$$

This equation can be expanded to include the corporate concentration for a given raw material in one combined term (additive). The revised supply risk equation is shown in Equation 8, where the variable $HHI_{i_{company}}$ is the corporate concentration for raw material i. As described above, the HHI is the sum of the squared market shares of the firms in the market, i.e. usually corporate concentration could be rewritten as $HHI_{i_{company}} = \sum_c (s_{i\_company})^2$.

Equation 8: Revised supply risk formula including corporate concentration (marked in blue)

$$SR_i = \sigma_i \cdot (1 - \rho_i) \cdot [\, HHI_{i_{company}} + \sum_c (s_{ic})^2 \cdot WGI_{ic} \,]$$

Note that the concentration at the country level is weighted based on a country rating (WGI or EPI; only WGI is shown above). It is not clear whether this can and should be done for companies such that Equation 8 must be revisited prior to including into the quantitative methodology. In addition, the threshold would have to be revised.

Alternatively, company concentration could be considered in a separate analysis, e.g. using the existing supply risk equation. This has the disadvantage of not providing a composite score for supply risk and adding an additional dimension to the analysis, increasing the perceived complexity of the exercise. In practical terms, however, this would simplify the approach because:

(a) data on corporate concentration is not available for all candidate raw materials; thus the analysis would only be performed where data is available and a separate scaling and threshold would be defined for this analysis[a].

(b) the scores can be interpreted independently in a similar way as the scores for governance and environmental performance are currently interpreted.

---

[a] Otherwise, a double threshold would have to be set for those raw materials where the analysis includes corporate concentration and those where this is not possible.

(c) no large adjustments to previous analysis would be necessary to ensure comparability.

Price volatility
As discussed in Section 5.5.1 the price volatility analysis has produced some useful and interesting results that could be directly applied within the overall analysis. This would complement the metric "economic importance" by providing an estimate of the economic impact of price disruptions. Annual pricing data for all of the materials of interest is available from the USGS or other sources, and an established formula exists for computing price volatility. This metric could, therefore, add significant richness to the current methodology and can also be applied reasonably easily to future studies, and potentially retrospectively.

A decision, however, would be needed on the precise mathematical derivation and formula to be applied. In the simplest terms, low price volatility might act as a "risk-reducing filter", rather in the same way that recycling rates and substitutability have been applied to the supply risk formula. For these metrics, the results have been scaled to lie between nought and one. However, in practice most of these figures lie in the range 0.5 - 1. We would recommend a similar approach here in order to avoid over-emphasising the importance of the price volatility metric in the final calculation. One suggestion would be to scale the volatility values by dividing through by the square root of T (time). For the values calculated in section 5.5.1 this would scale the results to lie between 0.03 and 0.60. This approach also allows for the possibility of changing the length of the time period analysed without altering the magnitude of the results. This would appear to be the least arbitrary option for scaling the results, though other options, such as scaling to 1 are also possible. The revised formula is therefore that in Equation 9, which no longer contains the term √T as that has been cancelled out in the division. This can then be used to multiply through the economic importance formula to calculate the economic impact for the raw material (Equation 10). One weakness in this formula is that is assumes that price volatilities have the same impact on all mega-sectors which might not be correct.

Equation 9: Revised historical price volatility formula

$$Volatility = STDEV \cdot \left(\ln \frac{P_t}{P_{t-1}}\right)$$

$$STDEV = \sqrt{\frac{1}{T}\sum_{t}^{T}(P_t - \bar{P})^2}$$

Equation 10: Revised economic importance formula – i.e. to calculate economic impact

$$EI_i = \sum_{s} A_{is} Q_s \cdot Volatility_i$$

Annex I – Sector specific discussions

Raw Materials and their criticality in the European defence sector

Some initial conclusions from the European Defence Agency's Analysis
On the grounds of internal work and a set of studies for the defence sector, an initial, non-exhaustive view on raw materials for defence supply chains and their criticality is described below. These studies cover criticalities in supply chains of a variety of defence technologies, products and capabilities.
The effort is made to get a view on the gaps for military capabilities and to be able to mitigate, reduce or eliminate reliance on outside (non-EU) suppliers for critical technologies in the security and defence environment. This has been thoroughly done for the ammunitions, for electronic components and to a certain extent for the defence aerospace sector - all key sectors as they affect the operational capabilities of the Armed Forces in Europe.

Those studies consider all forms of non-EU dependencies with a focus on those that are critical and leading to ever-increasing dependencies if not addressed: market-oriented dependencies, raw materials, specific components not available in EU, regulation, and the loss of engineering know-how.
Guaranteed access to raw materials and security of supply is important for all industries in Europe, but has a particular importance for the defence sector as it affects security and operational autonomy.
This resulted in the following, albeit incomplete picture for defence in Europe:

1. **Copper, Tungsten and Molybdenum**
    a) Domain of dependency: ammunitions: material for ballast, fragments generators and shape charges, nozzle throats and jet vanes (jet engine components).
    b) Related equipment: Thermal Vapor Compression systems, Long duration motors, anti-armour warheads, aircraft interception warhead and kinetic penetrator.
    c) Cause of dependency: European suppliers (Austria, France and Finland) get the raw material from outside of Europe.
    d) Risk: dependence of the supply for high quality and high performance products.

2. **Rare Earths**. Most used in the defence industry are; dysprosium, erbium, europium, gadolinium, neodymium, yttrium and praseodymium
    a) Domain of dependency: in ammunitions, aerospace, military surveillance systems, and military motors for catalytic converters, permanent magnets, battery cells, nuclear batteries, lasers and X-ray tubes.
    b) Related equipment: Motors, actuators.
    c) Cause of dependency: European producers are fully dependent on China for the raw material.
    d) Risk: unavailability of the materials.

3. **Gallium**
    a) Domain of dependency: electronic components, integrated circuits, printed circuit boards (PCB); high power switching.
    b) Related equipment: semiconductor components (in form of GaAs & GaN) for high power electronics in Radars, Communication and Electronic Warfare (Phased Array) Antennas; power conversion for increase of power integration density and efficiency (transversal use for defence systems and platforms), LED (Light Emitting Diodes).
    c) Cause of dependency: production predominantly outside of Europe; demand most likely increasing.
    d) Risk: limited availability, increase in demand and price.

4. **Titanium**
    a) Domain of dependency: aerospace applications for fixed-wing aircrafts and helicopters; missile systems; naval vessels.
    b) Related equipment: used on frames to reduce weight and increase durability in extreme conditions.
    c) Causes of dependency: existing range of suppliers but Russia and China dominant with over 40% of global production.
    d) Risk: currently no substitute for titanium in most military and aerospace applications, risk of increase in demand and price.

Other raw materials used in jet engine components and missile parts are *Niobium, Beryllium* (also for radars), *Tantalum* as well as *Cobalt*. The *Platinum Group Metals* are used for electronic devices, Germanium for infrared detectors, thermal imaging cameras, optical fibres, and magnesium for warheads. Although not critical in wider economic terms, the use of the following raw materials are of importance to defence aerospace applications: Titanium (see above), *Rhenium* for military jet engines, and *Molybdenum, Vanadium and Chromium* are extensively used in aircraft components and jet engines in particular.

References:
2009 EDA study ' Discotech European Roadmap in electronic and photonic components for Defence'
2011 EDA study 'Ammunition non-EU dependencies'
2012 EDA study 'How to ensure Tomorrow's Military Aerospace Supply Chain'

Critical raw materials in the energy technologies

Background

In order to tackle climate change, to increase energy supply security and to foster the sustainability and competitiveness of the European economy, the EU has made the transition to a low-carbon economy a central policy priority. To ensure this, the EU created the Strategic Energy Technology Plan (SET-Plan) with the aim to accelerate the development of low-carbon energy technologies throughout the EU in support of their subsequent large-scale deployment by 2020[a,b]. The SET-Plan prioritised six technologies: nuclear fission, solar photovoltaics (PV) and concentrated solar power (CSP), wind, bioenergy, carbon capture and storage (CCS) and the electricity grids. The EU also committed itself to reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050. The Commission has since analysed the pathway towards the 2050 targets and their implications within its EU Energy Roadmap 2050[c,d].

Critical metals in low-carbon energy technologies

In a first study conducted by the JRC in 2011 (Critical Metals in Strategic Energy Technologies), critical metals were identified, which could become a bottleneck to the supply-chain of the low-carbon energy technologies addressed by the SET-Plan.[e] Sixty metals (i.e. metallic elements, metallic minerals and metalloids) are considered; only iron, aluminium and radioactive elements (used as fuel in nuclear plants) were specifically excluded. Graphite was also included, reflecting its status as one of the critical raw materials identified by the EU Raw Materials Initiative. Fourteen metals were identified to be a cause for concern. After taking into account market and geopolitical parameters, five metals were labelled "critical", namely tellurium, indium, gallium, neodymium and dysprosium. The potential supply chain constraints for these materials were most applicable to the deployment of wind and PV energy technologies.

---

[a] European Council conclusions adopted on the basis of the Commission's Energy Package, e.g. the Communications: An Energy Policy for Europe COM(2007)1, Limiting Global Climate Change to 2 degrees Celsius—The way ahead for 2020 and beyond, COM(2007)2, Brussels.

[b] A European Strategic Energy Technology Plan (SET-Plan), Towards a low carbon future, COM(2007)723, Brussels.

[c] A roadmap for moving to a competitive low carbon economy in 2050,COM(2011)112, Brussels.

[d] Energy Roadmap 2050, COM(2011)885/2, Brussels.

[e] EU JRC (2011), Assessing metals as Supply Chain Bottlenecks in Priority Energy Technologies

In a follow-up study, other energy and low-carbon technologies are investigated that not only play an important role in the EU's path towards decarbonisation but also may compete for the same metals as identified in the six SET-Plan technologies.[a] Eleven technologies were analysed including fuel cells, electricity storage, electric vehicles and lighting. Where possible, the study modelled the implications for materials demand as a result of the scenarios described in the EU Energy Roadmap 2050. Consequently, the results obtained in the first study were updated to reflect the data that has become available in the roadmap.

The study found that eight metals have a high criticality rating and are therefore classified as “critical”. These are the six rare earth elements (dysprosium, europium, terbium, yttrium, praseodymium and neodymium), and the two metals gallium and tellurium. Four metals (graphite, rhenium, indium and platinum) are found to have a medium-to-high rating, suggesting that the market conditions for these metals should be monitored in case the markets for these metals deteriorate thereby increasing the risk of supply chain bottlenecks. The applications, i.e. technologies, of particular concern are electric vehicles, wind and solar energy, and lighting. Ways of mitigating the supply-chain risks for the critical metals were considered. These fall into three categories: increasing primary supply, re-use/recycling and substitution.

Further research
A number of topics were identified as possibly meriting further research. These include:

- conducting further studies to look at raw materials requirements for hybrid and electric vehicles for a wider range of technology uptake and penetration scenarios
- developing new and more detailed scenarios for the uptake and technology mix of options for stationary energy storage
- undertaking similar studies in defence and aerospace
- improving statistics on the contribution of recycling to world production for a number of metals
- investigating the contribution of greater traceability and transparency to reducing raw materials supply risk.

Materials of concern to the ICT sector

Technologies in the ICT are increasing reliant on a growing number of different materials. Many of the materials that are now used have historically been low production volume, speciality metals, with only niche uses. Whilst often small in terms of volume of materials used, they play an irreplaceable role in a product’s function. Therefore a developing ICT sector places growing pressure on the access to these materials. This has led to concerns over supply of certain metals which are linked to the ICT sector, those particularly highlighted by DG Connect include:

- rare earth elements, specifically dysprosium, erbium, europium, neodymium, terbium and yttrium
- indium
- hafnium
- gallium
- germanium.

Projects arising from DG Research have sought to address these concerns through the development of alternative technologies that are not reliant on these materials, or through enabling recovery of these materials through recycling and related actions.

---

[a] EC JRC (2013) Critical Metals in the Path towards the decarbonisation of the EU Energy Sector

Oakdene Hollins Ltd
Pembroke Court
22-28 Cambridge Street
Aylesbury
Buckinghamshire
HP20 1RS

T: +44 (0)1296 423915
E: admin@oakdenehollins.co.uk
www.oakdenehollins.co.uk
www.remanufacturing.org.uk

Registered in England No. 2937129