Sus Mat Crit

Teaching Resources on the Sustainable Management of Critical Raw Materials

Trainer's Manual for

Criticality

March 2020

eit RawMaterials ACADEMY

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Table of Contents

1. Context and Introduction to Training

This booklet is supplementing the teaching materials and the set of further supporting booklets that have been developed to support teachers in conducting training courses related to the sustainable management of critical raw materials.

SusCritMat aims to educate people from Master's student level up, both in industry and academia about important aspects of sustainable critical raw materials. In a novel concept, it introduces courses on these complex and interdisciplinary topics in a modular structure, adaptable to a variety of different formats and accessible to both students and managers in industry. These courses will develop new skills, which will help participants to better understand the impact and role of critical raw materials in the whole value chain; enabling them to identify and mitigate risks. Understanding the bigger picture and the interconnected nature of global business and society is increasingly necessary to and valued by industry.

SusCritMat is an EU-funded project that brings together the technical and pedagogical expertise of leading educational institutions and business partners. It uses and creates teaching materials which can be combined into different course formats.

This training kit presents the key messages related with the sustainable management of critical raw materials in three major sections:

- Introduction to criticality (including criticality assessment, global resource supply chains, geopolitical factors, and economics of metals)
- Analysis of criticality (including material flows, scenario planning, and life cycle assessment)
- Solutions (including responsible sourcing, circularity indicators, circular product design, and good practice examples)

In particular, the solutions part will be in the focus. The intention is to underline the possibilities that are available to approach and implement a circular economy for critical raw materials and the products bearing these. Doing so the concrete actions, i.e. the things that can be done, are highlighted, instead of only mentioning all sorts of associated problems or barriers in the context of CRMs.

The overall goal of the Summer School for Educators is to qualify the participants to teach the topics themselves. Therefore, the school does not only provide an introduction and improved insight into selected thematic issues, but to also deliver a set of teaching materials "ready-to-use".

- Learning targets that will be reached after having taught the courses
- Presentations on the specific topics including also notes on how to present the slides and key messages.
- Group work exercises including the task or question to work on, if applicable further reading on the methodology and the solutions in case of tasks requiring calculations.
- Assessment questions and the correct answers for each specific topic.
- Additional reading for each topic.

1.1 Training Materials List

The *SusCritMat project* developed the following teaching materials for the Summer School:

Basics
Critical Resources for Emerging Technologies
Criticality
Supply Chain Resilience
Supply Risk Factors
Circularity
Circular Economy
Characterizing the Urban Mine
Circular Business Models
Waste Management and Recycling Potential
Closing Loops on Product Level
Governance
Geopolitical Aspects
Metals & CRM Scenarios
Restricted Substances Legislation
Impact on Society and the Environment
Sustainability Assessment
Responsible Mining
Responsible Sourcing / Certification
Environmental Aspects
Sustainable Materials Usage
CRM and Sustainable Development
Tools
MFA - Material Flow Management
Good Use of Data
LCA – Life Cycle Assessment
Process Models based on LCA

1.2 Suggested Timetable

The agenda contains a recommended timing for the lecture and exercises. However, depending on the pre-existing knowledge or group size the time can be extended.

Lecture: 45 minutes
Group work exercise: 30 minutes
Live quiz: 10 minutes
Discussion on quiz results: 15 minutes

1.3 Key Messages

Restrictions to the global supply for mineral raw materials (MRMs) are more related to ACCESS to MRMs than to geological availability (how much is out there).

Access is constrained by economic, geopolitical, environmental and social factors.

Criticality assessments are qualitative in nature: there is no "correct" method, but different methods are suited to different end users and scales of space and time.

A thorough market analysis, including information regarding ongoing mineral exploration projects, is often more informative than theoretical criticality calculations based on various formulae.

1.4 Learning Objectives

List the learning objectives for your course here.

This session will provide learners with:

- A review of concepts underlying criticality assessments
- An overview of methodologies
- Clarify possibilities and limitations of criticality estimations
- Illustrations with reference to specific critical raw materials

1.5 Additional Reading

Literature list listed according to topics (**priority readings in bold**)

Blengini, G. A., et al., 2017. EU methodology for critical raw material assessment : Policy needs and proposed solutions for incremental improvements. Resources Policy, 53, 12-19.

Buijs, B., Sievers, H., Tercero Espinoza, L. 2012. Limits to the critical raw materials approach. Proceedings of the Institution of Civil Engineers - Waste and Resource Management, 165(4), 201-208.

EC, 2017. Study on the review of the list of Critical Raw Materials. Final Report. European Commission.

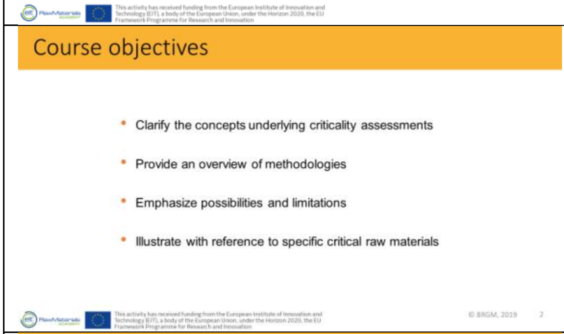
Frenzel et al., 2017. Raw material 'criticality" – sense or nonsense? Journal of Physics, D: Applied Physics, 50.

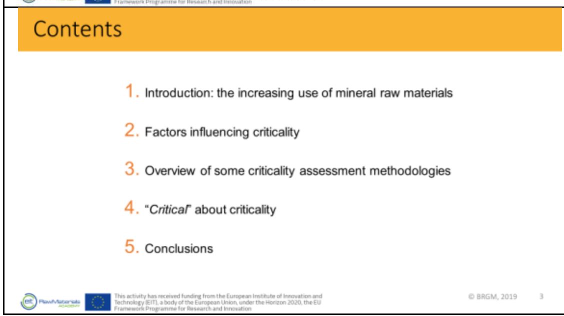
Graedel, T. E. et al., 2012. Methodology of metal criticality determination. Environmental Science & Technology, 46, 1063-1070.

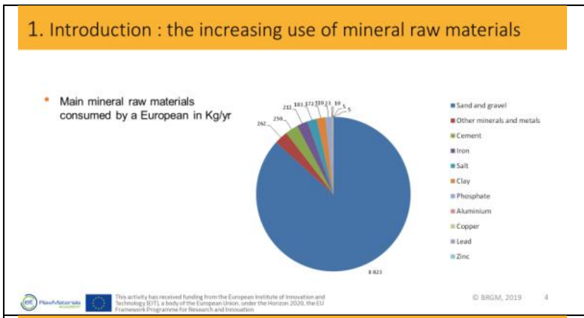
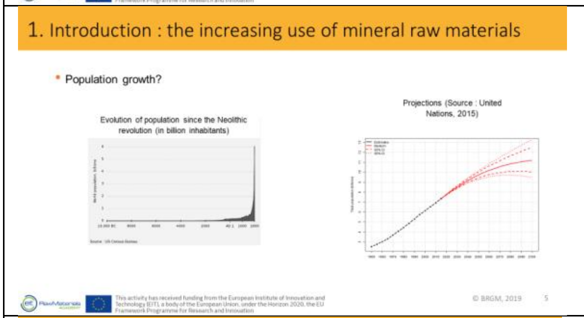
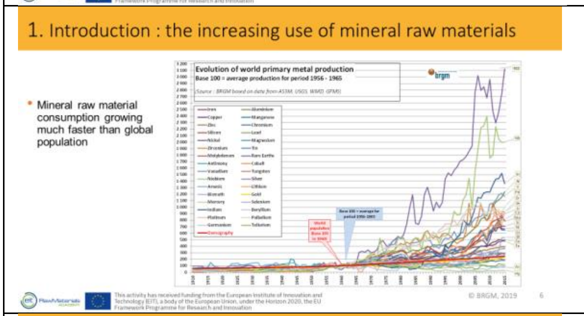
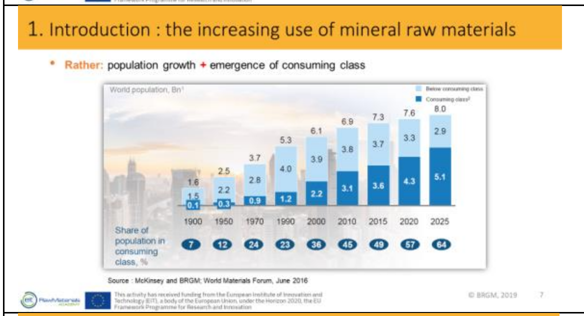
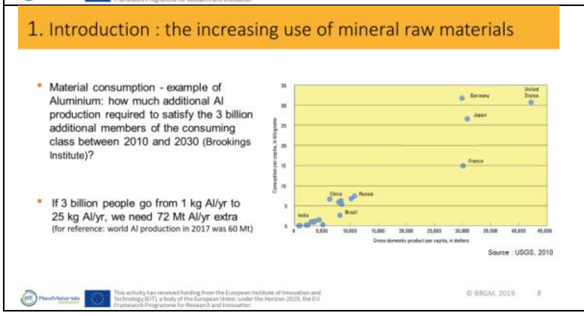
Graedel, T. E. & Reck, B. K., 2016. Six years of criticality assessments. What have we learned so far? Journal of Industrial Ecology, 20(4), 692-699.

NRC, 2008. Minerals, Critical minerals, and the U.S. Economy. Report of National Research Council. Washington, DC: The National Academies Press.

2. Slides and Notes





<table>
<tr>
<td>
</td>
<td>The main mineral raw material consumption is of sand and gravel
Other minerals and metals comprises all that is not indicated (rare metals, precious metals, etc.)</td>
</tr>
<tr>
<td>
</td>
<td>Exponential growth of world population since industrial revolution, exploitation of fossil fuels, which enabled the agricultural revolution</td>
</tr>
<tr>
<td>
</td>
<td>We can’t explain explosion of mineral raw material consumption only by population growth</td>
</tr>
<tr>
<td>
</td>
<td>1: Historical values for 1820 through 1990 estimated by Homi Kharas,2010 – 2025 estimates by McKinsey Global Instutute
2: Defined as people with daily disposable income above $10 at PPP. Population below consuming class defined as individuals with disposable income below $10 at PPP (Power Purchasing Parity)</td>
</tr>
<tr>
<td>
</td>
<td>Illustrates the significant difference between Indutrialised versus emerging economies in terms of raw material consumption per capita.</td>
</tr>
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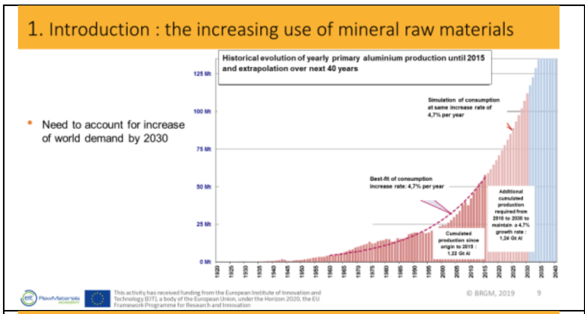
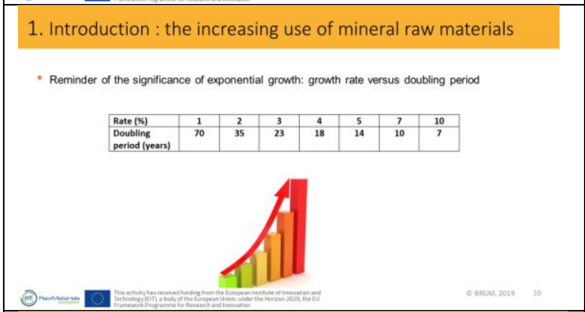
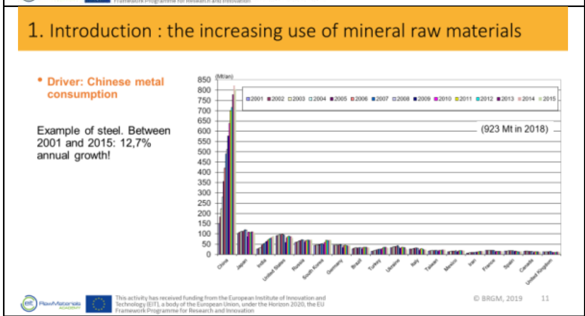
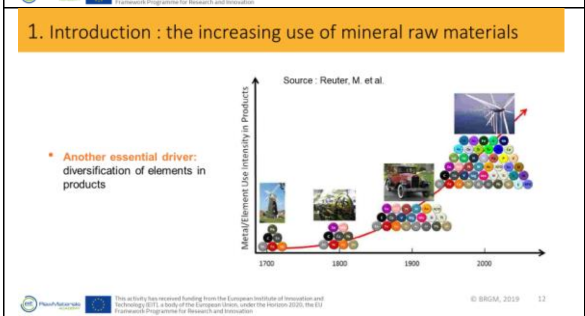
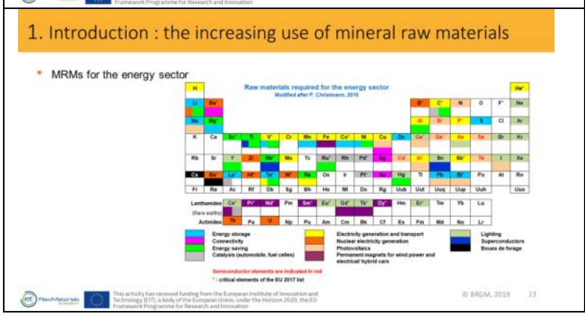
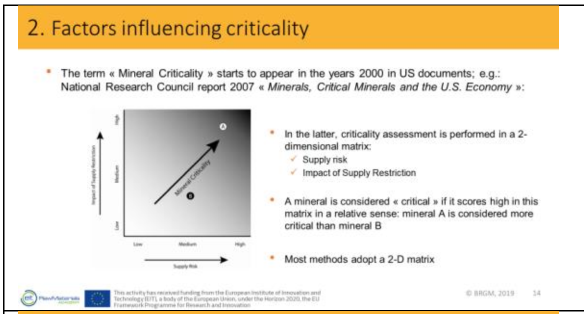
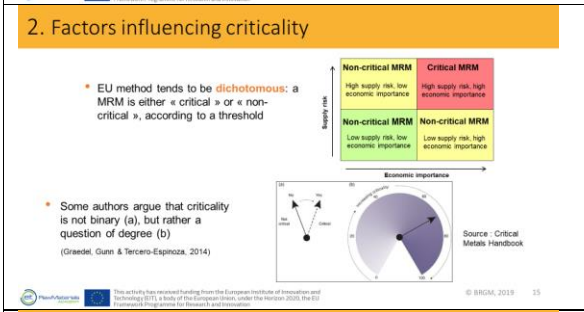
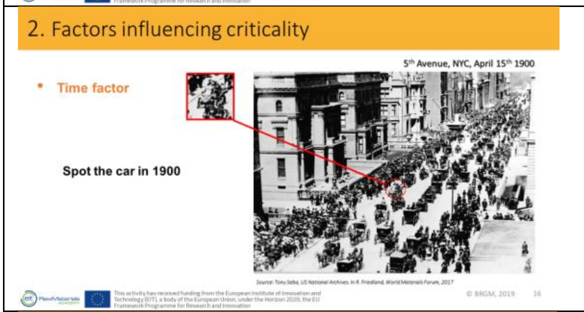
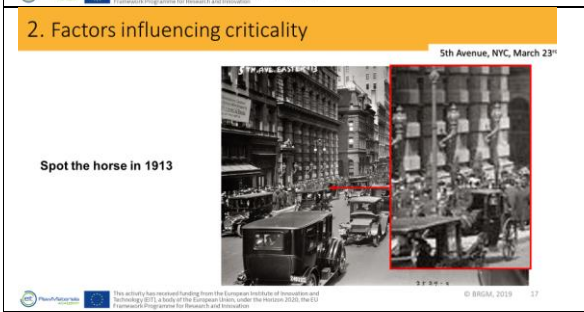
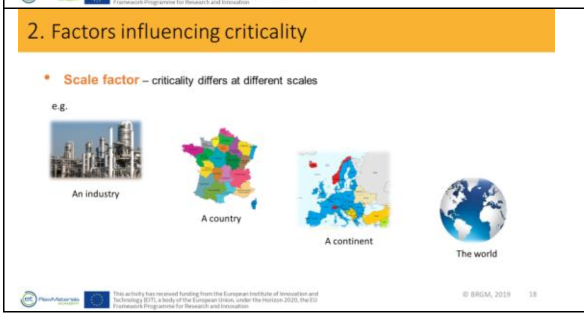
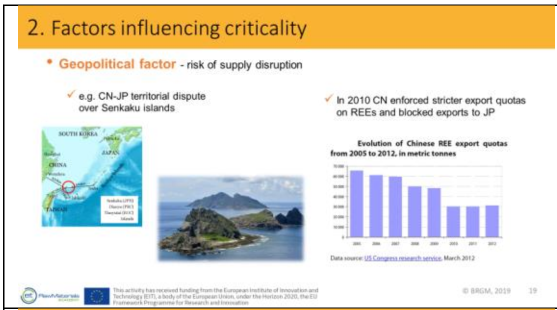
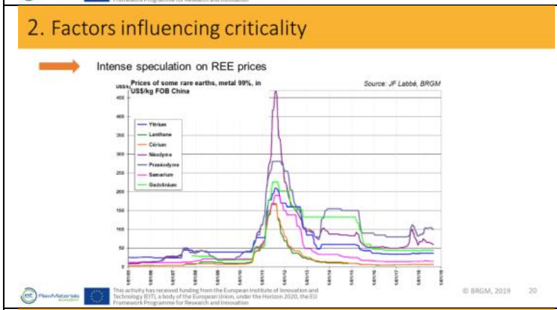
	Graph also illustrates limits of exponential growth. This curve cannot be extended forever, due to environmental, social, energy, … constraints
	Illustration: assuming we start (year 1) with a 100 ton/year production rate, we will have 200 tons/year in year 23 with a 3% growth rate, in year 14 with a 5% growth rate and in year 7 with a 10% growth rate.
	Key message : China has been a major driver of the World's economy and has consumed enormous amounts of mineral raw materials to fuel its growth.
	While during the 18th century, energy-producing technology used about 6 elements of the Mendeleiev Table, in the 21st century the technology uses about 50 elements.
	The same message as previoulsy is illustrated, in more detail, by this slide. Nearly all the elements of Mendeleiev's Table are involved in the production of energy.

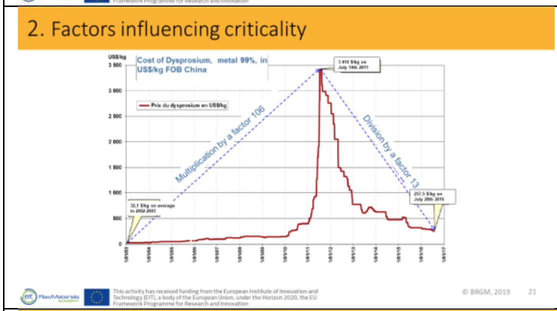
	A critical mineral or raw material is (i) important for one or several industrial sectors and (ii) is at risk of supply shortage.
	There is no unambiguous critality threshold. It is a question of choice.
	There was only one motor vehicle on 5th avenue on April 15th 1900
	While on March 23rd 1913, only 13 years later, there was only one horse-driven carriage
	A specific industry, in a specific country, will have supply-chain risks that are very different from those of an entire country or of a continent. Therefore criticality is a relative notion.



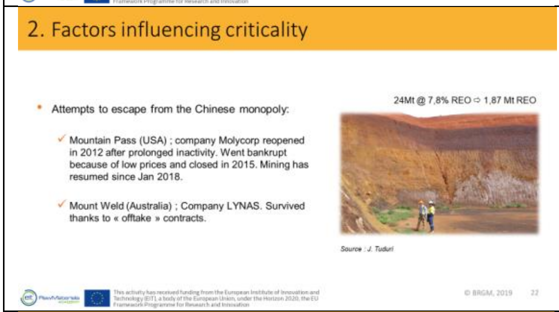
Both China and Japan claim sovereignty over the Senkaku islands. In 2010 the dispute climaxed which led to retaliatory measures from China, who blocked all rare earth exports to Japan.

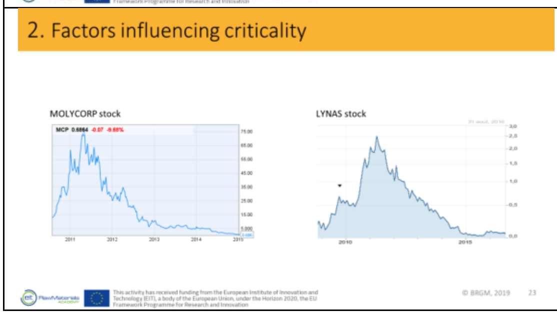


Prices of rare earth metals (here so-called « Light » rare earths) skyrocketted

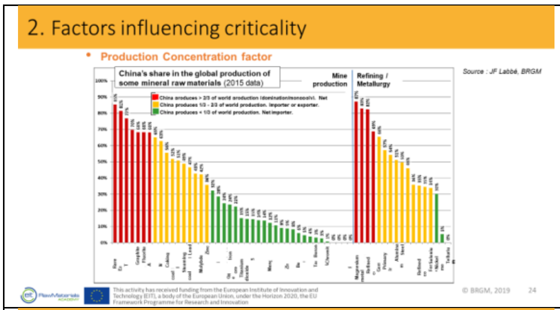
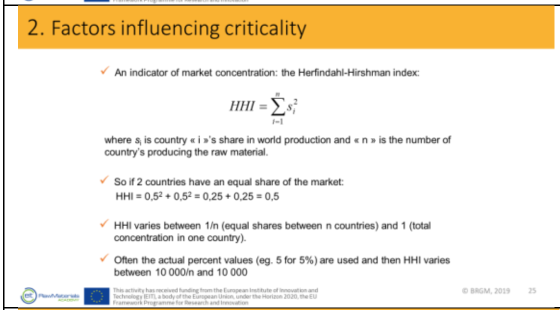
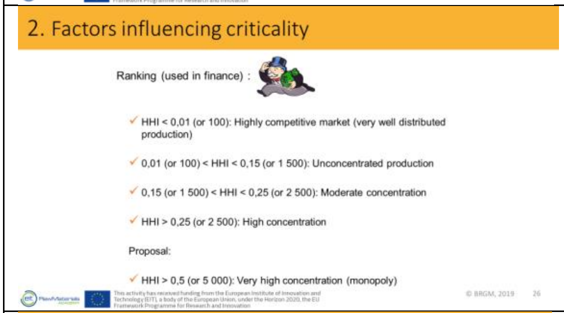
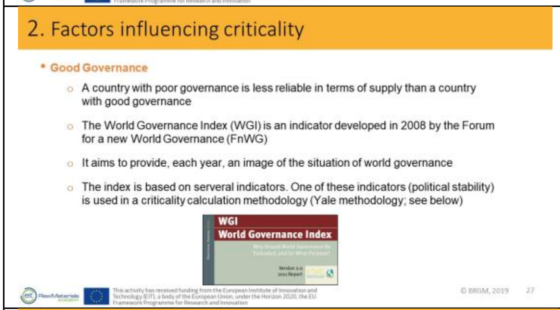
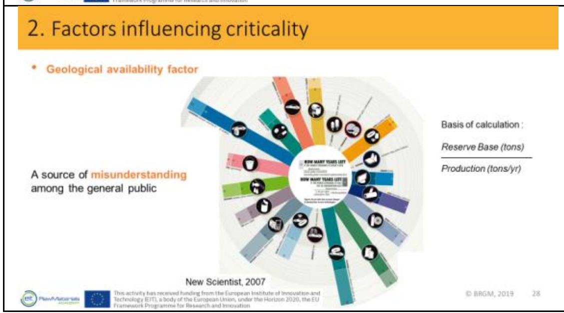


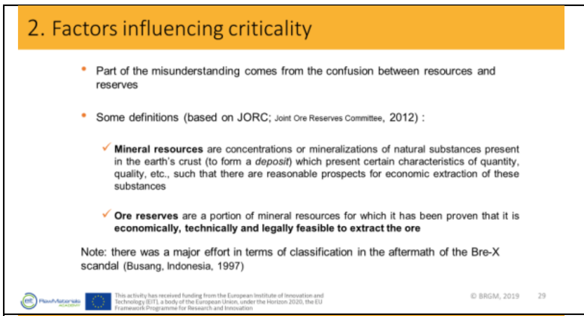
This one shows a Heavy Rare Earth (Dysprosium: an essential component of permanent magnets).



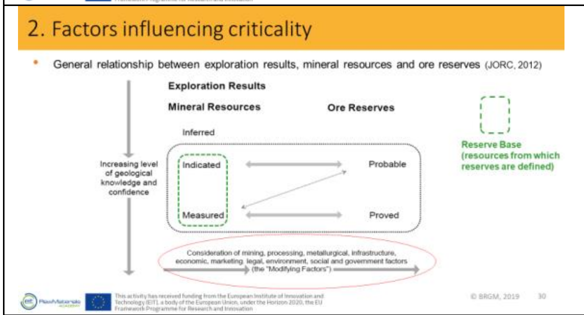


Illustrates the « speculation bubble » effect. China has different (long term) stategy, not so dependent on short-term market performance

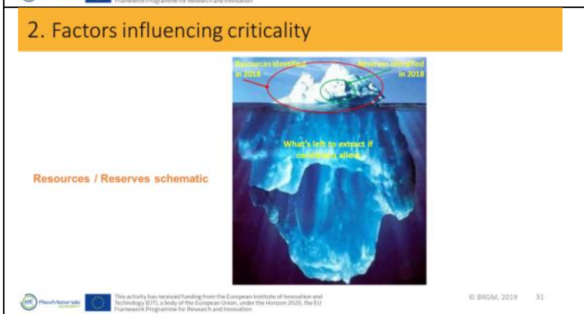
	Illustrates importance of value chain: some countries may be key players in refining but not in mining
	
	The proposal is relevant for some strategic metals (see Hands On exercise)
	Political stability is a key indicator in the evaluation of criticality, as it has a strong influence on supply risk.
	This graphic, published in the media, claims to provide the number of years until several mineral raw materials « run out »

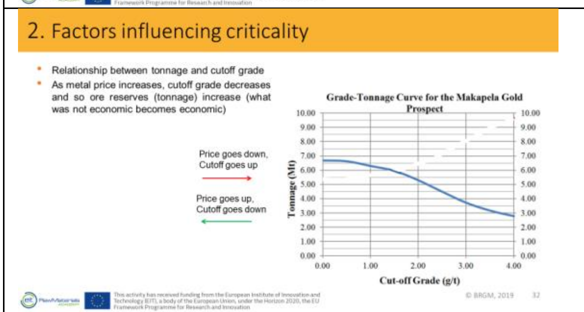


In order to talk sense about geological availability, it is necessary to understand some basic concepts of mining geology.

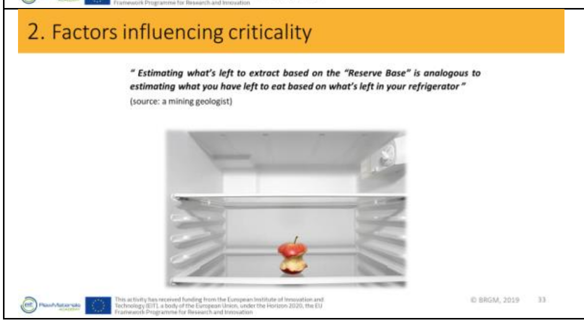


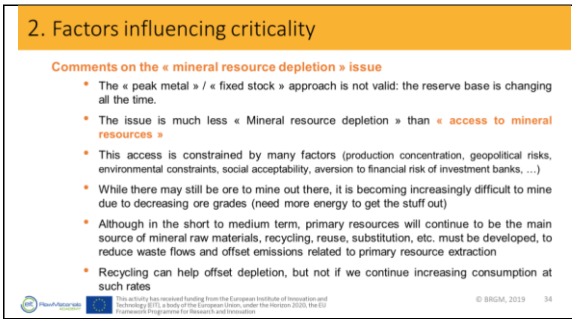
The « Reserve Base », that appears in the simple calculation of mineral depletion time, is estimated from indicated and measured mineral resources. This depends on the level of mineral exploration: it is definitely not « all that's out there »

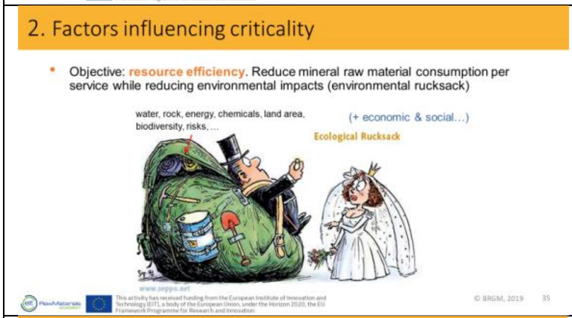


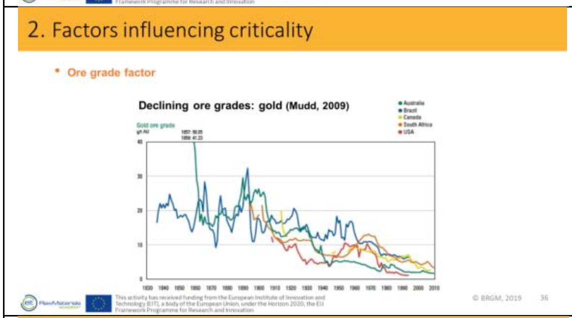


The cutoff grade is the ore grade (concentration) below which the miner decides not to extract because he won't make a profit

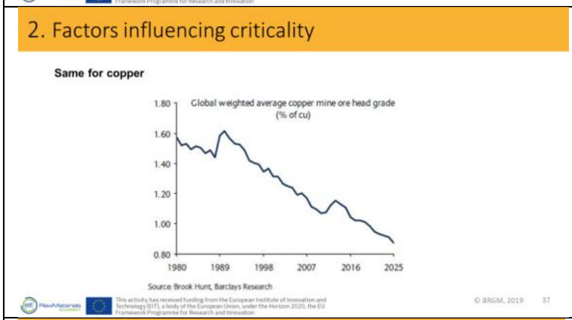




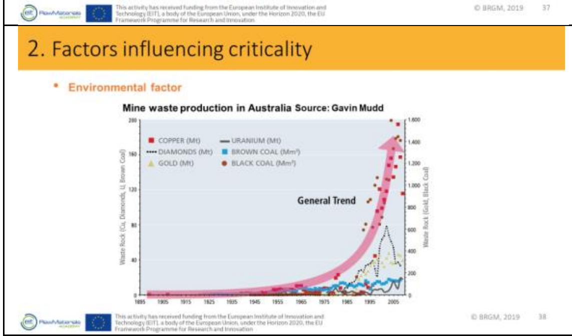




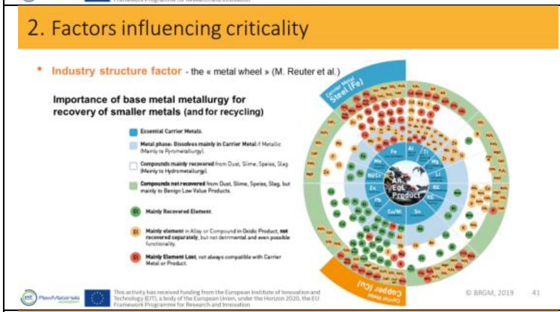
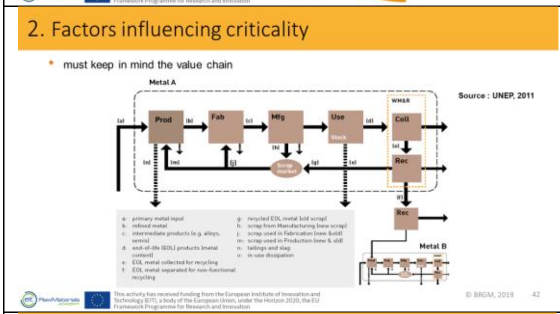
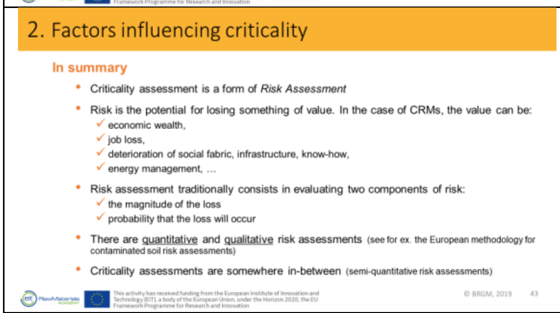
Over time, miners have progressively mined mineral deposits with lower and lower ore grades (metal concentrations). Because they mined the richest deposits first.

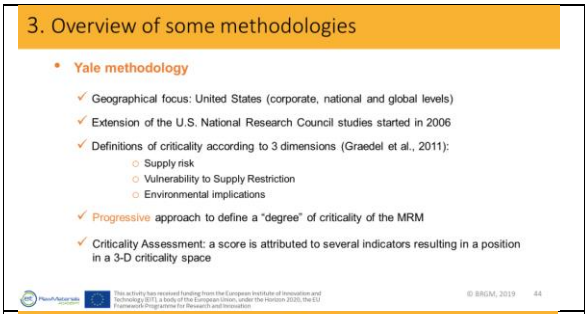


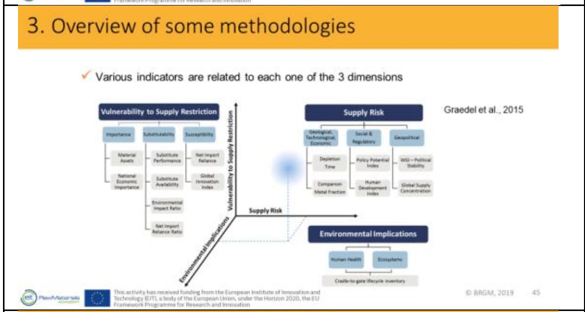
Same holds for copper. There will come a point, where the metal concentration in the ore will be so low that it won't be worth mining anymore (cost of energy required to mine will be too high).

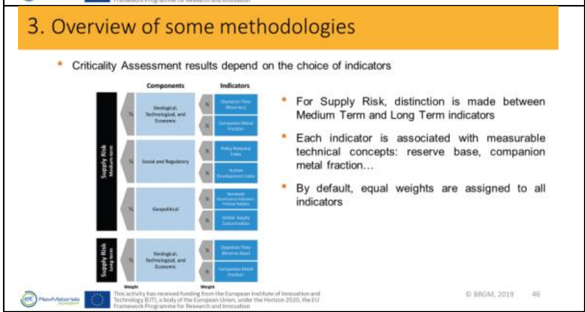


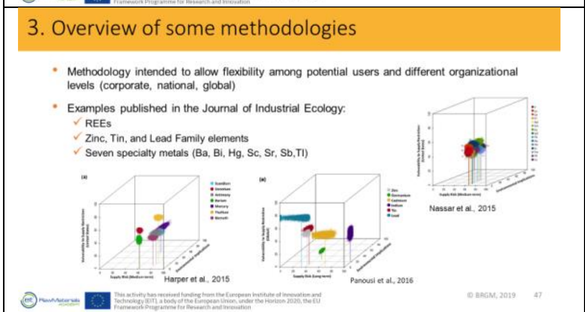
When a miner extracts ore, he is extracting a small percentage of metal (for example copper) and a large percent of mine waste (see course on responsible mining). Mine waste reprensents an environmental hazard.

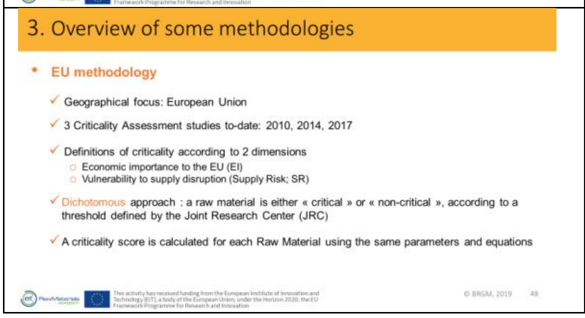
	This photo shows the impressive scale of mine waste generation in the extractive industry
	The « Social Licence to Operate » of the mining industry is seriously under pressure, especially in the wake of major accidents such as the Brumadinho tailings facility accident in January 2019 (200 casualties).
	« Rich » graphic although difficult to read. Key message is that many critical metals are not produced for themselves but as byproducts of « carrier metals »
	Metal B is non-functional recycling: metal A is downcycled and is no longer recycled for its specific properties. All explanations are in the UNEP 2011 report. Metal Recycling Opportunities, Limits, Infrastructure.
	


3. Overview of some methodologies
Yale methodology
Geographical focus: United States (corporate, national and global levels)
Extension of the U.S. National Research Council studies started in 2006
Definitions of criticality according to 3 dimensions (Graedel et al., 2011):
Supply risk
Vulnerability to Supply Restriction
Environmental implications
Progressive approach to define a "degree" of criticality of the MRM
Criticality Assessment: a score is attributed to several indicators resulting in a position in a 3-D criticality space
© BRGM, 2019 44


3. Overview of some methodologies
Various indicators are related to each one of the 3 dimensions
Vulnerability to Supply Restriction
Supply Risk
Environmental Implications
Graedel et al., 2015
© BRGM, 2019 45


3. Overview of some methodologies
Criticality Assessment results depend on the choice of indicators
Components
Indicators
For Supply Risk, distinction is made between Medium Term and Long Term indicators
Each indicator is associated with measurable technical concepts: reserve base, companion metal fraction…
By default, equal weights are assigned to all indicators
© BRGM, 2019 46


3. Overview of some methodologies
Methodology intended to allow flexibility among potential users and different organizational levels (corporate, national, global)
Examples published in the Journal of Industrial Ecology:
REEs
Zinc, Tin, and Lead Family elements
Seven specialty metals (Ba, Bi, Hg, Sc, Sr, Sb,Tl)
Nassar et al., 2015
Harper et al., 2015
Panousi et al., 2016
© BRGM, 2019 47


3. Overview of some methodologies
EU methodology
Geographical focus: European Union
3 Criticality Assessment studies to-date: 2010, 2014, 2017
Definitions of criticality according to 2 dimensions
Economic importance to the EU (EI)
Vulnerability to supply disruption (Supply Risk; SR)
Dichotomous approach : a raw material is either « critical » or « non-critical », according to a threshold defined by the Joint Research Center (JRC)
A criticality score is calculated for each Raw Material using the same parameters and equations
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3. Overview of some methodologies

- 2017 methodology revision was motivated by the need to:
  - ✓ Better capture risks of trade distortion such as:
    - Export taxes
    - Physical quotas
    - Export prohibitions
  - ✓ Address more adequately the entire value chain (identify bottlenecks in the steps of extraction or metallurgy, shifts in supply concentration, etc.)
  - ✓ Differentiate Global supply and European supply
  - ✓ Better account for supply from secondary sources and for substitution potentials
  - ✓ Have a more transparent allocation of raw material uses to NACE sectors

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation
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3. Overview of some methodologies

- In 2017, the measure of Economic Importance (EI) was calculated from: $EI = \frac{10}{Q_{max}} \sum_s A_s Q_s SI_{EI}$

Where:
A_s = share of metal demand in application "s" relative to total demand
Q_s = Gross Value Added (GVA) of 2-digit NACE sector allocated to application "s"
Q_{max} = Largest GVA of all 2-digit NACE sectors (scaling factor)
SI_{EI} = Substitutability Index related to Economic Importance

- Supply Risk (SR) was calculated from: $SR = \left[(HHI_{WGI-t})_{GS} \frac{IR}{2} + (HHI_{WGI-t})_{EU28}\left(1 - \frac{IR}{2}\right)\right](1 - EoL_{RIR})\, SI_{SR}$

Where:
$(HHI_{WGI-t})_{GS}$ = Herfindahl-Hirschmann Index for Global Supply, taking into account World Governance Index score and a trade factor (t)
$(HHI_{WGI-t})_{EU28}$ = Herfindahl-Hirschmann Index for EU 28 Supply, taking into account World Governance Index score and a trade factor
IR = Import Reliance (%)
EoL_{RIR} = End of Life recycling input rate
SI_{SR} = Substitutability Index related to Supply Risk

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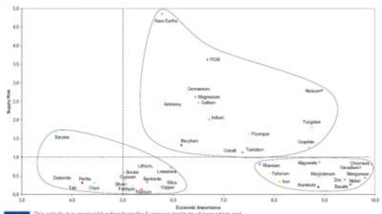
3. Overview of some methodologies

EU CRM list 2010



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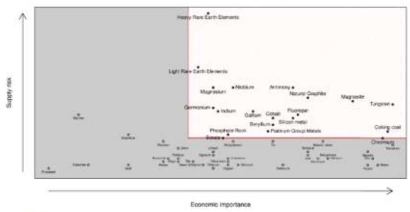
3. Overview of some methodologies

EU CRM list 2014



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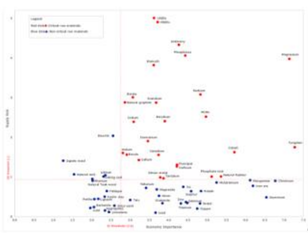
3. Overview of some methodologies

EU CRM list 2017



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3. Overview of some methodologies

Question: why does Scandium have more Economic Importance than Lithium?

3. Overview of some methodologies

- According to USGS, the global supply and consumption of Sc is around 10-15 tons per year.
- Scandium uses in 2016:
  - ✓ The main uses were in Al-Sc alloys and in solid oxide fuel cells (SOFC)
  - ✓ Al-Sc alloys are produced for sporting goods (luxury golf clubs)
  - ✓ Al-Sc alloys are considered a potential substitute for Titanium (expensive) in e.g. aircrafts. But this is currently at *R&D* stage and no aircraft industry would suffer from Sc-supply disruption
  - ✓ Sc is used in small quantities in a number of electronic applications
  - ✓ Other minor uses: ceramics, lasers, lighting, …

- So Scandium is a niche market

See hands-on exercise…

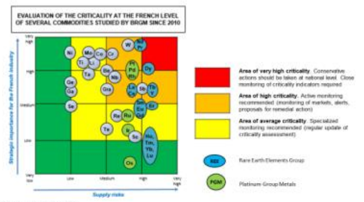
3. Overview of some methodologies

- Some advantages of the EU Criticality assessment methodology
  - ✓ Important communication tool for policy makers and (some) industrial companies
  - ✓ Transparency of the methodology and sources of data
  - ✓ Snapshot of the parameters affecting criticality of each specific Raw Material (at the time of the study), described in the additional Factsheets.
- Some drawbacks of the EU Criticality assessment methodology
  - ✓ Complexity of the formulas and constraints imposed by transparency (e.g. use of public data only) are not always compatible with the complexity of the markets at stake
  - ✓ Some parameters affecting criticality are omitted (see hands-on exercise)

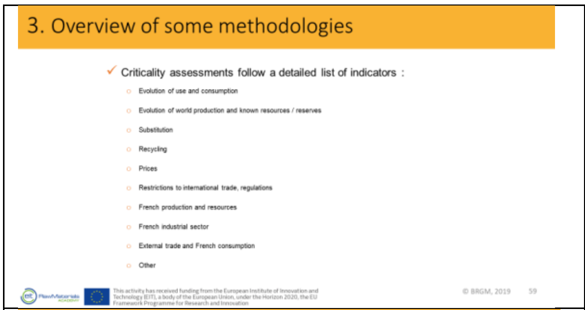
3. Overview of some methodologies

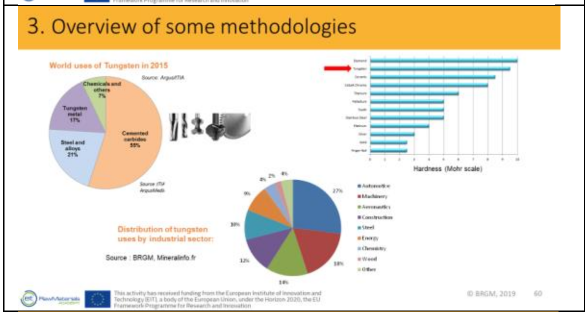
- **BRGM methodology**
  - ✓ Geographical focus: France
  - ✓ Criticality Assessment studies : About 20 CRM covered from 2010 to 2017, according to French governments' requests and priorities
  - ✓ Definitions of criticality according to 2 dimensions :
    - Strategic importance for the French industry (y-axis)
    - Supply risks (x-axis)
  - ✓ Progressive approach :
    - Not one but several thresholds to define the degree of exposure to the risks
    - No calculation but rather an indicative position based on several parameters and expert judgement
  - ✓ The objective is to give criticality indicators to policy makers and industry, as well as recommendations of actions to carry out

3. Overview of some methodologies

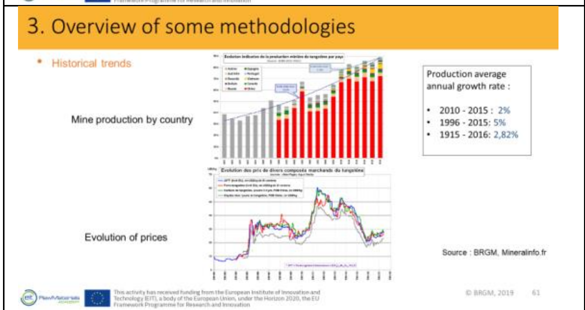


Source : BRGM, 2017

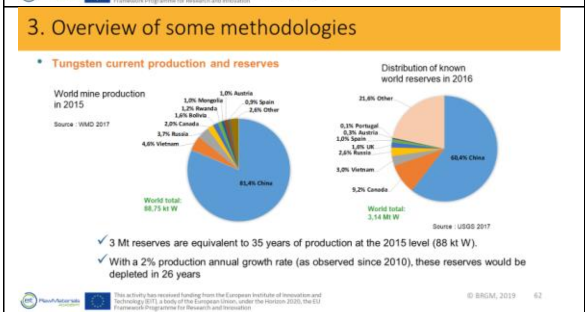




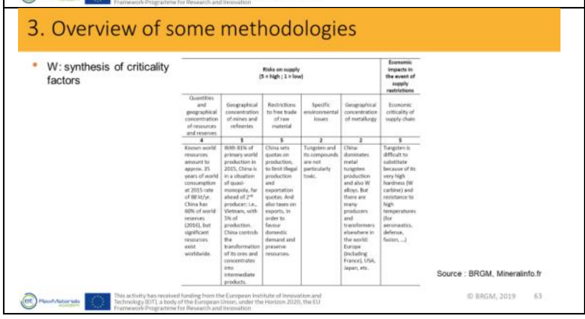
This illustrates the type of information collected to study a metal's criticality. Why is it important? Which industrial sectors use it? In what type of products? Etc.



Which countries are producing it? How are the prices evolving?



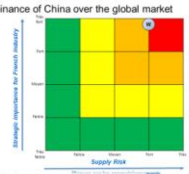
What are the known « geological stocks »? Where are they located in the world?



The BRGM methodology is a multi-factor analysis, where scores are assigned to factors that influence criticality.

3. Overview of some methodologies

- Conclusion: very high criticality of Tungsten (W) at the French level due in particular to:
  - ✓ The wide variety of uses in industry (e.g. Tungsten carbide tools)
  - ✓ The strong dominance of China over the global market



Source : BRGM, Mineralinfo.fr

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4. Critical about criticality

- Several critical appraisals of criticality assessment methodologies in the literature. For example :

Topical Review

Raw material 'criticality'—sense or nonsense?

- This paper advocates a more "quantitative" approach to risk in criticality assessments.
- Difficulty: due to abovementioned diversity/complexity of risk factors, it is difficult to build a comprehensive quantitative "model" of factor interactions

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4. Critical about criticality

- Criticality is a dynamic, ever-changing characteristic of a MRM. Therefore assessments need to be periodically updated
- Regarding methodologies, we feel there should be more scope for feedback from industry/expert stakeholders before issuing CRM assessment results
- Before performing a criticality assessment, key questions are :
  - ✓ Critical for who?
  - ✓ Criticality for what? (decision-making)
- Past experience has shown benefits of criticality analyses especially at a corporate level. In particular when analyses have led to actions in terms of reducing company exposure to problematic elements
- Scope for a harmonized methodology?...
- Addressing uncertainties?...

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4. Critical about criticality

- Other example: Buijs et al. (see references). These authors identify the following limitations in the critical minerals approach:
  - ✓ Bias towards technology minerals by emphasizing (a) high-tech applications and (b) the role of market power of producers in small markets,
  - ✓ Lack of predictive power beyond the short term,
  - ✓ Failure to distinguish between short-term and long-term problems,
  - ✓ Tendency to overstate the economic impact of a possible supply disruption of 'critical' minerals,
  - ✓ Exaggerated focus on risks related to the mining and export of raw materials, but not on the larger production chain (e.g. refining, transport, and trade in semi-products).
- According to the authors, most of the minerals that historically have been classified as "critical", have in fact never caused significant problems (e.g. PGMs).
- An issue specific to the EC method will be addressed during the "hands-on" session

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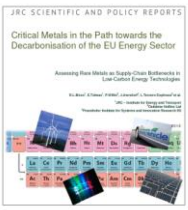
4. Critical about criticality

- Example of CRM list for specific applications:



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4. Critical about criticality

Illustrates importance of time factor: in 2013, Eu, Tb were considered highly critical

High	High-Medium	Medium	Medium-Low	Low
REE: Dy, Eu, Tb, Y	Graphite	REE: La, Ce, Sm, Gd	Lithium	Nickel
REE: Pr, Nd	Rhenium	Cobalt	Molybdenum	Lead
Gallium	Hafnium	Tantalum	Selenium	Gold
Tellurium	Germanium	Niobium	Silver	Cadmium
	Platinum	Vanadium		Copper
	Indium	Tin		
		Chromium		

Source : JRC, 2013

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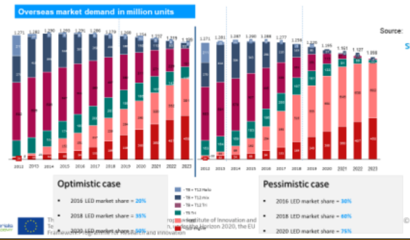
4. Critical about criticality

- But: fluorescent lighting has been rapidly superseded by LEDs



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4. Critical about criticality

- Phosphors containing Eu and Tb are now a very small share of the total market, which has much reduced their criticality

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5. Conclusions

- Restrictions to global supply of MRMs are more related to access to MRMs than to geological availability
- Access is limited primarily by economic, geopolitical, environmental and social factors
- Criticality assessments attempt to address the risk of supply disruption and economic/social damage through a multifactor ranking approach
- These methods are screening tools. Attempts to be « precisely quantitative » are limited by the diversity and complexity of factors
- Different methods deliver different results: there is no « correct » method; there is only *adequacy of methods with specific user needs*
- Therefore values can only be compared for a given methodology and in a relative sense

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References for further reading

- **Blengini, G. A., et al., 2017. EU methodology for critical raw material assessment : Policy needs and proposed solutions for incremental improvements. Resources Policy, 53, 12-19.**
- Buijs, B., Sievers, H., Tercero Espinoza, L. 2012. Limits to the critical raw materials approach. Proceedings of the Institution of Civil Engineers - Waste and Resource Management, 165(4), 201-208.
- EC, 2017. Study on the review of the list of Critical Raw Materials. Final Report. European Commission.
- Frenzel et al., 2017. Raw material 'criticality' – sense or nonsense? Journal of Physics, D: Applied Physics, 50.
- **Graedel, T. E. et al., 2012. Methodology of metal criticality determination. Environmental Science & Technology, 46, 1063-1070.**
- Graedel, T. E. & Reck, B. K., 2016. Six years of criticality assessments. What have we learned so far? Journal of Industrial Ecology, 20(4), 692-699.
- **NRC, 2008. Minerals, Critical minerals, and the U.S. Economy. Report of National Research Council. Washington, DC: The National Academies Press.**

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References in bold could be read in priority.

3. Exercises

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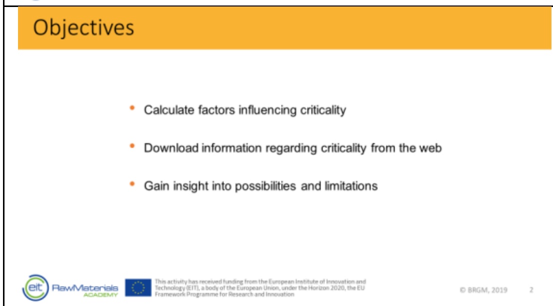
<tr><td>
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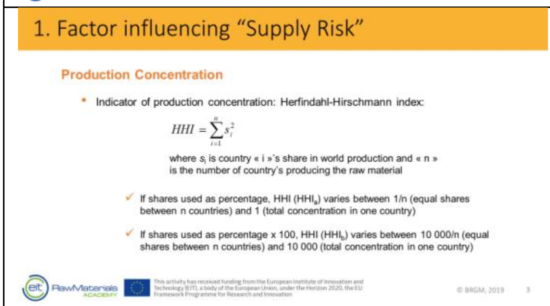
<tr><td>
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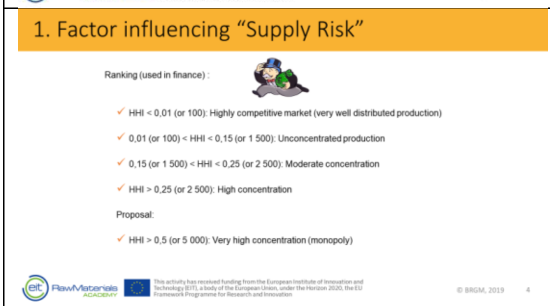
<tr><td>
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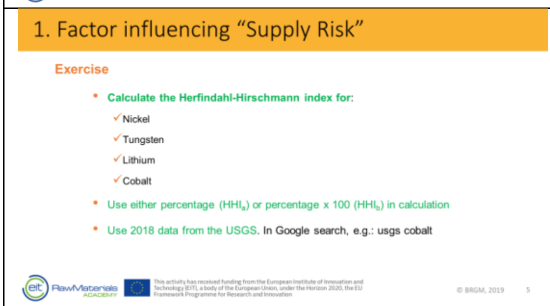
<tr><td>
</td><td>This exercise is of interest for data mining: the students search the internet to obtain the data and then apply the formula</td></tr>
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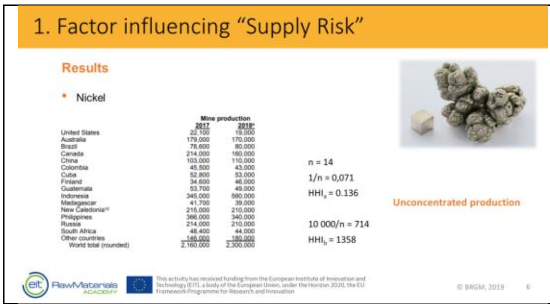

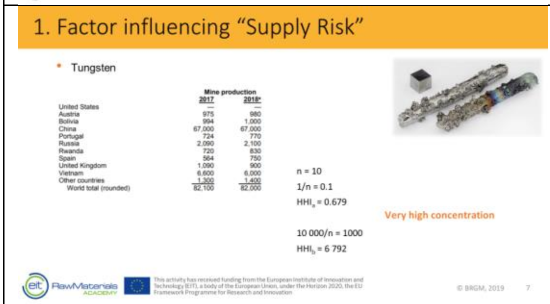

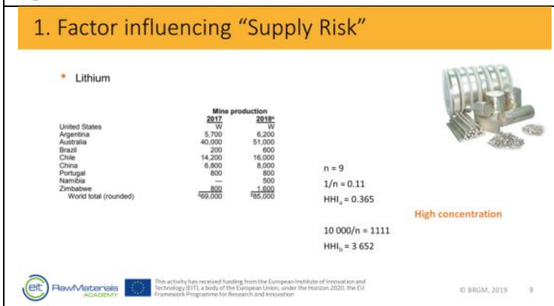

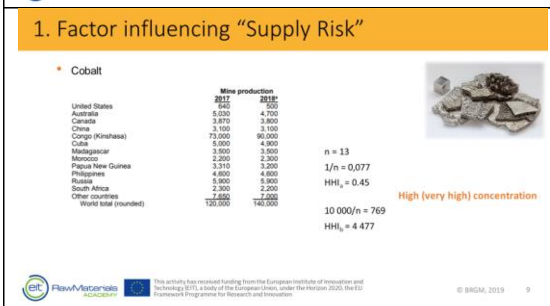

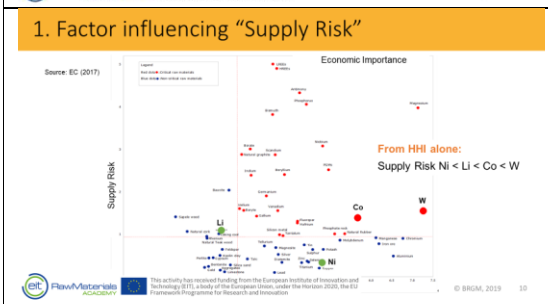

The students can see that based on the Herfindahl-Hirschman index, they obtain the same raking of supply risk as in the EC 2017 Report on critical materials

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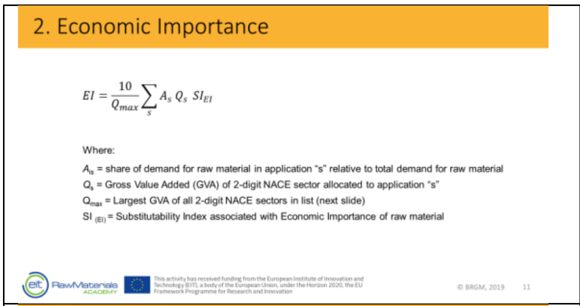

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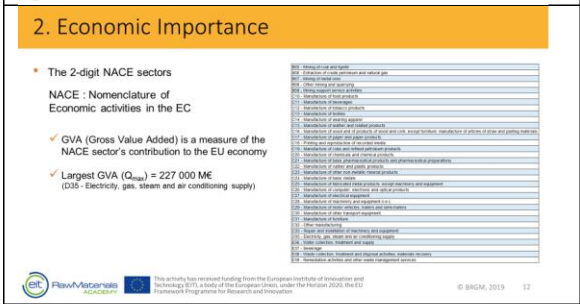

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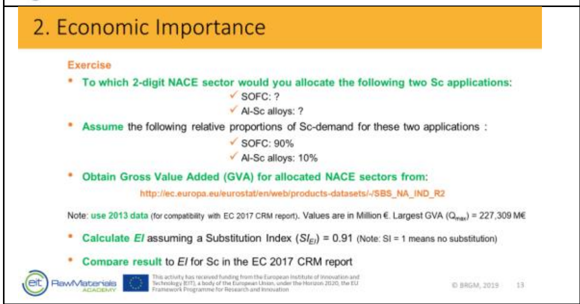

</td><td>Here the students are again going to look for data on the internet and they will be able to calculate the same values of Economic Importance as those of the EC 2017 report on critical materials</td></tr>
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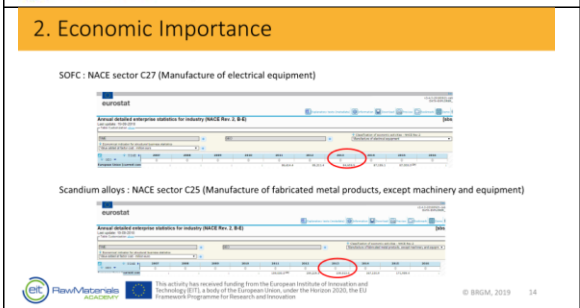

</td><td>These are screenshots of the pages with the required information</td></tr>
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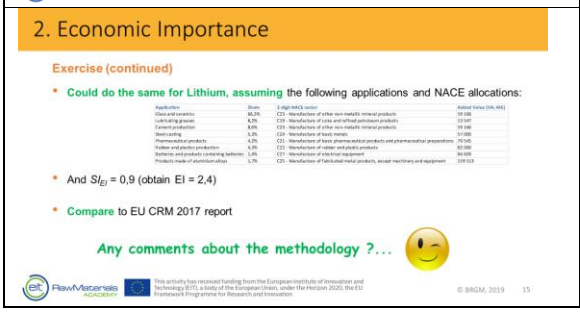

</td><td>Can do if time allows</td></tr>
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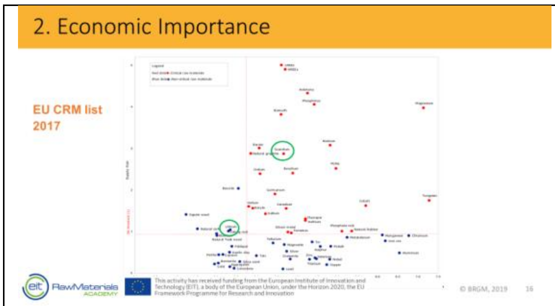
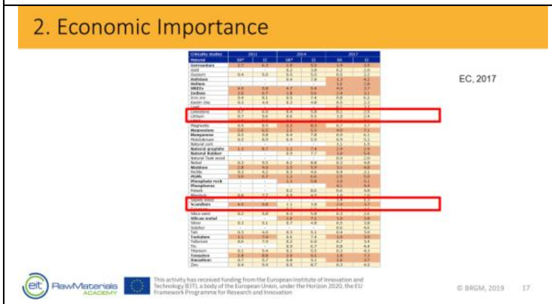
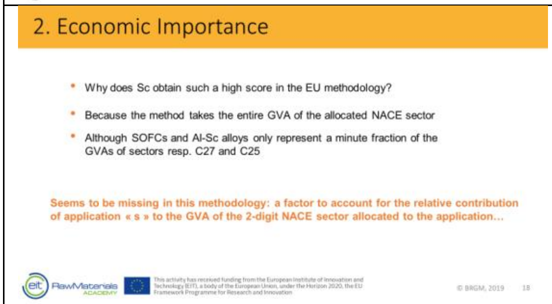
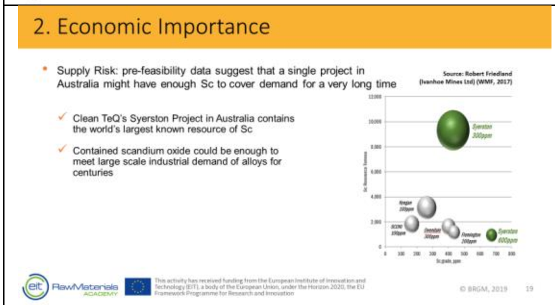
<tr><td>
</td><td>This graph highlights how Scandium scores higher in Economic Importance than Lithium. With the criticality thresholds selected by the Commission, Scandium appears to be critical while Lithium does not (which makes no sense at all…).</td></tr>
<tr><td>
</td><td>The same with the precise scores for economic importance</td></tr>
<tr><td>
</td><td>The explanation. For inexperienced group it may be difficult to pinpoint this major flaw in the methodology, so would have to be guided.</td></tr>
<tr><td>
</td><td>Puts the exercise in the perspective of real world exploration on Scandium. Indicated resources are abundant and criticality should not be a problem. Could also talk about Scandium in red muds from Aluminium industry</td></tr>
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4. Assessment Questions

Since the middle of the 20th century, world consumption of most mineral raw materials is:
Answer 1: Rapidly increasing (correct)
Answer 2: Rapidly decreasing
Answer 3: Stabilizing
Answer 4: Fluctuating

The following factor has the least real influence on criticality:
Answer 1: The estimated reserve base (correct)
Answer 2: Metal substitutability
Answer 3: Time scale of the analysis
Answer 4: Distribution of global metal production

Historically, metal contents in mined ores tend to:
Answer 1: Decrease (correct)
Answer 2: Increase
Answer 3: Stabilize
Answer 4: Fluctuate

Tungsten is critical because it is:
Answer 1: Essential in certain industries due to its hardness (correct)
Answer 2: A precious metal
Answer 3: Very useful for air pollution control
Answer 4: Used in permanent magnets for renewable energy

Tungsten is critical because it is:
Answer 1: Produced mainly by one country (China) (correct)
Answer 2: Becoming too expensive
Answer 3: Too difficult to mine
Answer 4: Has a high toxicity

Criticality of Europium has changed rapidly because:
Answer 1: It is much less in use since the advent of LED lamps (correct)
Answer 2: New Europium deposits have been discovered
Answer 3: It has become too expensive to use
Answer 4: It is increasingly rare

Criticality estimates are:
Answer 1: Relative estimates that depend on the method used (correct)
Answer 2: Probabilistic risk assessments
Answer 3: Precise and relatively well known for many metals
Answer 4: About as useful as cooked bus tickets

Calculations of global metal depletion times are typically wrong because:
Answer 1: They assume that there is a fixed metal stock to be mined (correct)
Answer 2: They don't take into account recycling
Answer 3: They don't take into account substitution
Answer 4: They don't consider the entire value chain

The price of rare earths skyrocketed in 2011 because:
Answer 1: Of speculation following Chinese restrictions on exports (correct)
Answer 2: Rivalry between producing countries
Answer 3: The discovery of new high-tech applications for rare earths
Answer 4: A sudden depletion in global rare earth reserves

Criticality is usually a 2-dimensional matrix considering:
Answer 1: Economic importance and supply risk (correct)
Answer 2: Supply risk and metal price
Answer 3: Economic importance and geological availability
Answer 4: Metal price and recycling potential

5. Acknowledgements and Authors

Dominique Guyonnet from BRGM prepared the teaching material for this session.

The following authors have prepared the complete teaching material kit for the SusCritMat Summer School for Educators and intend to provide an overview of major topics surrounding the sustainable management of critical raw materials:

Ruud Balkenende, TU Delft
Stefano Cucurachi, Uni Leiden
Andrea Gassmann, Fraunhofer IWKS
James Goddin, Granta Design
Gus Gunn, BGS
Dominique Guyonnet, BRGM
Alessandra Hool, ESM Foundation
Thibaut Maury, University of Bordeaux
David Peck, TU Delft
Dieuwertje Schrijvers, University of Bordeaux
Layla van Ellen, TU Delft
Tatiana Vakhitova, Granta Design
Ester van der Voet, Uni Leiden
Patrick Wäger, Empa
Steven Young, University of Waterloo

6. Citation

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7. Disclaimer

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