Teaching Resources on the Sustainable Management of Critical Raw Materials

Trainer's Manual for
Metals and Critical Raw Materials Scenarios

March 2020

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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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)

1.1 Training Materials List

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

Scenarios are tools to explore future developments. They can be used for many different purposes. In the Scenarios module, they are used to explore future resource use, with a focus on critical materials.

The training material for the Supply risk lecture consists of the following:

- A powerpoint presentation on scenarios for resources. This is meant for two lecture hours of 45 minutes. It is also possible to use part of the slides for a shorter period.
- A powerpoint presentation on scenarios for cobalt. Partly this contains similar material as the general scenario lecture slides, but mostly more specific information related to cobalt. These slides are sufficient for one lecture hour of 45 minutes.
- A powerpoint presentation on the urban mine for cobalt and lithium. In this powerpoint, the magnitude of the urban mine is explored and an argument is made to shift the attention from geological to urban mining. This presentation is good for one lecture hour of 45 minutes.
- A classroom exercise on scenario storyline development for cobalt, which consists of the last six slides of the powerpoint presentation on cobalt scenarios, as well as a hand-out document in Word. The exercise can be done in one lecture hour of 45 minutes. It works best in groups of 4-7 people, and would need at least 3 groups to become interesting.

1.3 Key Messages for the Scenarios module

The most important message of this module is twofold: scenarios are an essential and very powerful tool to explore the future, but we should never interpret such an exploration as a prediction of the future. Debates around scenarios often focus on the question on how “reliable” or “realistic” such a scenario is. The answer is: no scenario is reliable or realistic, and predicting the future is not a meaningful exercise. The value of scenarios is in thinking about what might be, not what will be. What might be under certain conditions, under specific assumptions, if we assume things to go on as they are, if we assume radical changes, etc. That allows us to identify roads we would like to travel, or roads we really would like to avoid.

Scenarios for resources are still in their infancy. Some first attempts are now appearing, for example generated by the OECD and by the UN-International Resource Panel. Scenarios for critical resources are even more scarce and, given the nature of these resources, also very difficult to imagine. Especially here, what-if scenarios can be useful. The lecture slides bring together the kind of scenario analysis that exists on the topic of critical materials, and the classroom exercise explores these topics even further.

1.4 Learning Objectives for the scenarios module

The learning outcomes for the Scenarios module are the following:

- Understanding the value as well as the limitations of scenario analysis
- Obtaining insight in present activities around scenario analysis of resources
- Experimenting with the first step in scenario analysis: the development of scenario storylines

1.5 Additional Reading for Session

- International Resource Panel, 2019. Global Resources Outlook 2019: https://www.resourcepanel.org/reports/global-resources-outlook
- OECD, 2018: Global Material Resources Outlook to 2060 – Economic Drivers and Environmental Consequences.
- A package of information on the Shared Socio-economic Pathway (SSP) scenarios can be found here: https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about

2 Slides and Notes

The **first set of slides** is on scenarios, and focuses later on on scenarios for raw materials. The lecture slides start out with scoping and defining the concept. Some characteristics of scenarios, and some choices to be made at the start, are shown then. As with other types of analysis, such choices very much depend on what the purpose is of the scenario exercise. What exactly the question is that should be answered determines whole set of choices:

- Long-term vs. Short-term
- Baseline vs. Transition
- Quantitative vs. Qualitative
- Partial / local vs Comprehensive / global
- Forecasting vs. Backcasting
- Normative vs Exploratory

Quite a few slides are dedicated to scenarios for climate change, which may be the most relevant example to build on for scenarios for resources as well.

The next topic is the development of future scenarios for resources at global level. Two types of quantification are introduced: top-down and bottom-up. Another dichotomy is the difference between demand scenarios and supply scenarios. Demand scenarios tell us how much of a certain resource is needed, while supply scenarios can be specific on how demand is met, via which production routes, and with what share of secondary production.

The last part of the slides is about critical materials. It is argued that they are a special case, for which the concept of “baseline” has no meaning. Examples are shown of scenarios for different CRMs.

The **second set of slides** is about scenarios for cobalt. To some extent it repeats the information already covered in the general scenarios lecture slides, but much more briefly. The first thirteen slides therefore can be skipped if the scenarios lecture is already given earlier. It is argued that top-down modelling is not a good option for materials that are so technology-specific, therefore, bottom-up modelling is the only option. Some forecasts are shown developed by industry, that rarely go beyond 2025. A very few studies go beyond 2030, these are shown as well. It is clear that such forecasts rely on assumptions that we know not to be true, i.e. that technology will not change.

The last part of these slides contain the introduction of the classroom exercise: developing storylines for cobalt (see further down below).

The **third set of slides** is on the urban mine of cobalt and lithium. In a circular economy, society's material basis will be the urban mine. Presently there is very little insight in the magnitude of the urban mine, for these and other materials. The slides contain a first exploration of whether or not the urban mine for cobalt and lithium is significant. In the absence of professional and reviewed literature, we use students' research to support the line of reasoning. Three scale levels are considered: global, EU and municipal – the municipality of The Hague, a Dutch city. An attempt is made to compare the urban mine with the geological resources and reserves. The conclusion is that the urban mine might already be considerable in size. In future it is expected to grow further, thereby growing into a relevant resource for a circular economy. It is therefore very much worth exploring in more detail.

Slides for **Scenarios for Critical Raw Materials**

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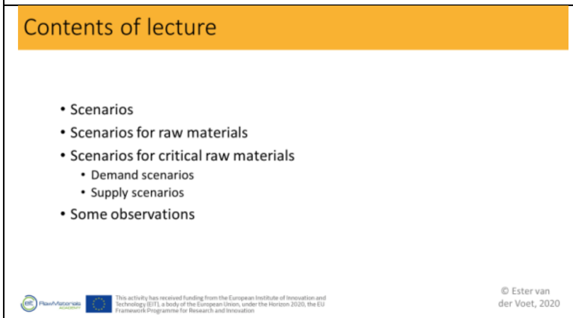
<tr><td>
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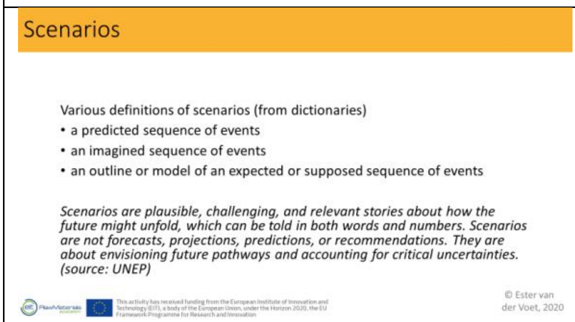
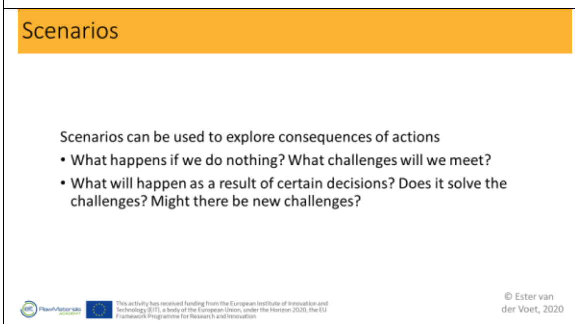
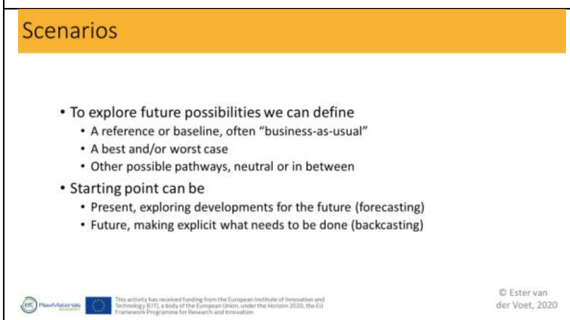
<tr><td>
</td><td>Make clear scenarios are NOT predictions, despite what the dictionaries say. Scenarios are about the future, and therefore by definition inaccurate. We use the UNEP definition.</td></tr>
<tr><td>
</td><td>The added value of scenario analysis is not to try and be as "correct" as possible about the future, but to use scenarios as a tool to envision consequences of certain decisions or identify a "desirable" way to go.</td></tr>
<tr><td>
</td><td>Explain different types of scenarios, to make clear there is not just one. A BAU is useful as a reference, to offset the other scenarios that may show more extreme developments. Forecasting vs backcasting: forecasting starts from the present and explores pathways into the future, while backcasting starts from the future – often w</td></tr>
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<td>desired future – and explores pathways back to the present. Forecasting answers questions like: what would happen if …? Backcasting answers questions like: what is needed to get where we would like to be?</td>
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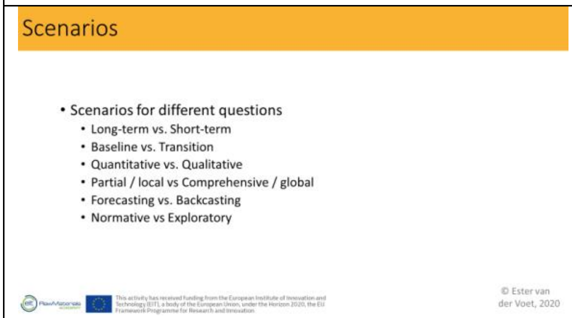
<td>
</td>
<td>This is to scope the breadth of things that can be categorised under the heading of Scenarios. Note that often a baseline scenario is used to offset the other, more transition oriented scenarios. Especially relevant to acknowledge that quantification is not always necessary: sometimes, the storyline may already be sufficient information. All depends on who wants to use scenarios for what purpose. For large-scale policy supporting scenarios such as the IPCC climate scenarios, quantification is needed. We want to know the effectiveness of certain changes, and the magnitude of necessary changes to stay within the 2 degrees. For such scenarios, it is important to have some (policy) goal, aim, or target as a reference point.</td>
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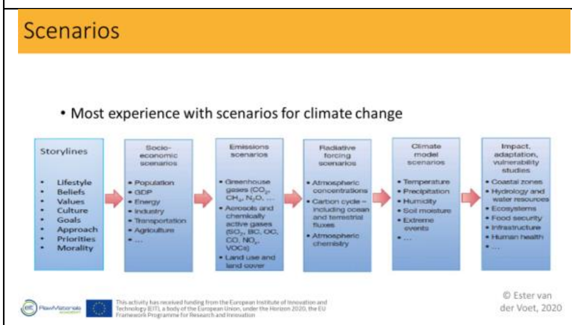
<td>
</td>
<td>This is the sequence of modelling events for the climate scenarios. They clearly follow the DPSIR approach embedded in the main global level Integrated Assessment models. The R (Responses) is missing here, a crucial item in any scenario that has to support policy decisions.</td>
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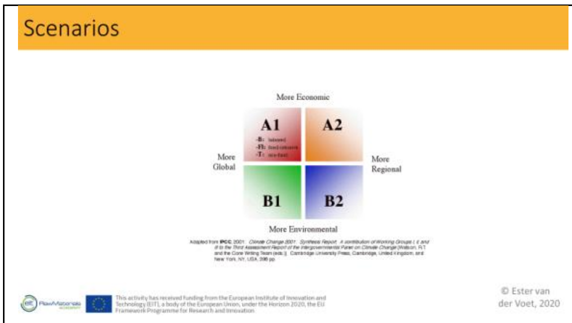
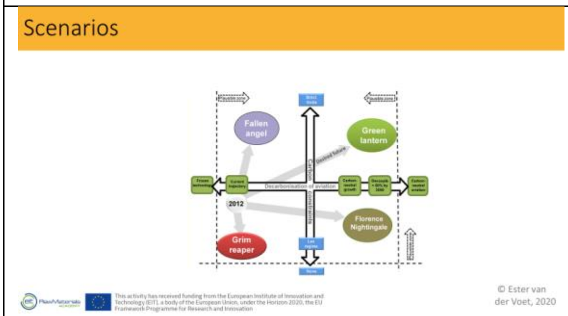
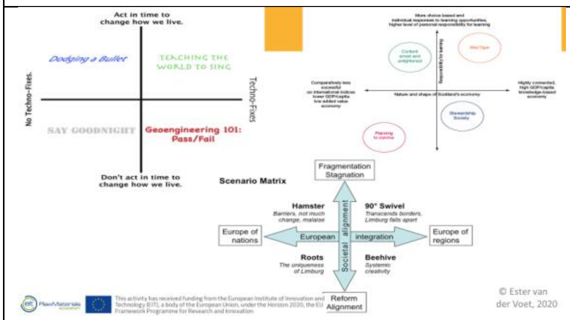


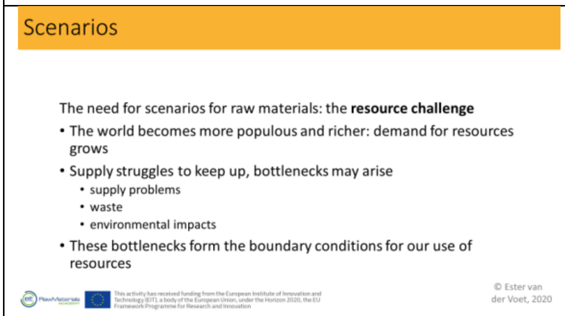
Many scenario efforts use the Quadrants approach to typify the main underlying developments in two axis. This helps in visualisation but also in understanding the main influential variables. This quadrant picture comes from the 2001 IPCC report on climate change scenarios. It is based on two axes: scale level of decision making, and emphasis on economic development vs environmental sustainability. In a later stage this Quadrants approach has been abandoned by IPCC in favour of the SSP scenarios that describe different socio-economic developments without an environmental axis. Each of those SSP scenarios has a two-degree variant.



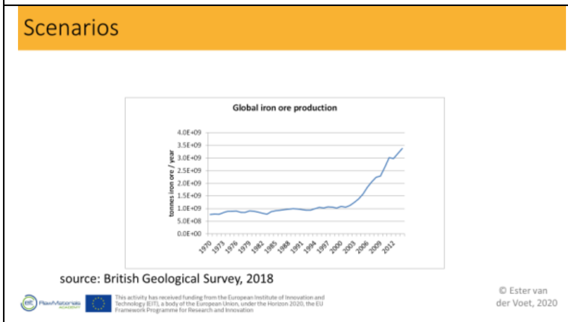
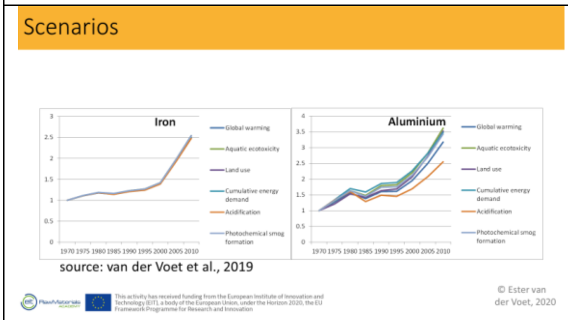
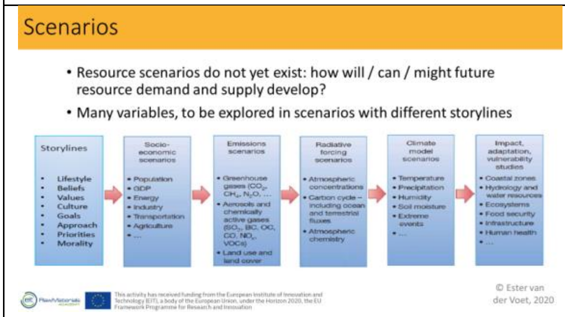
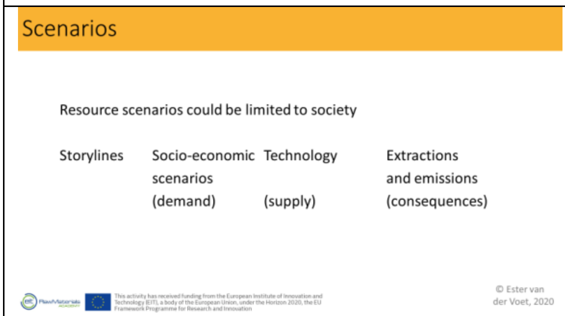
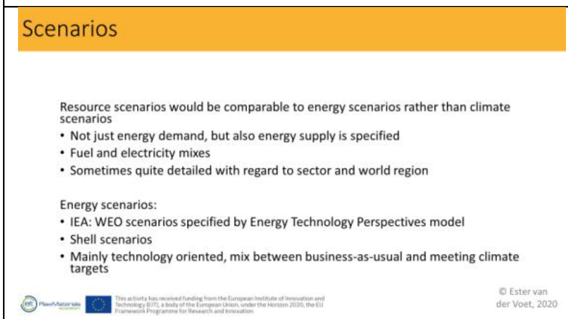
Examples of quadrants, including the characterisation of the scenarios following from it.

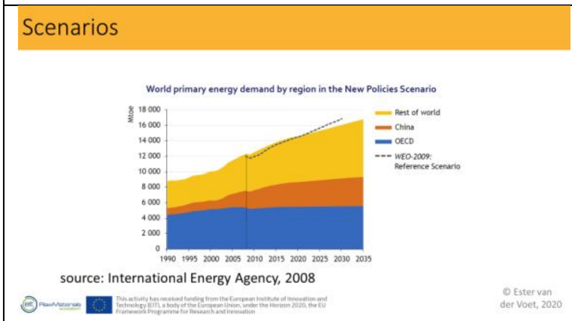
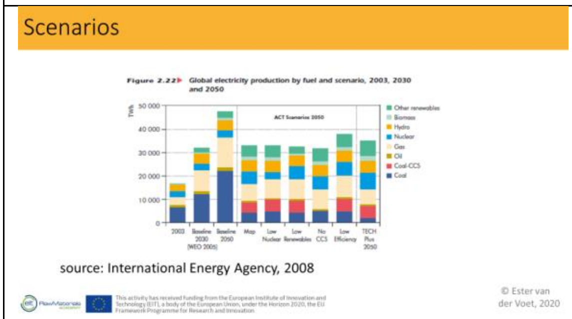
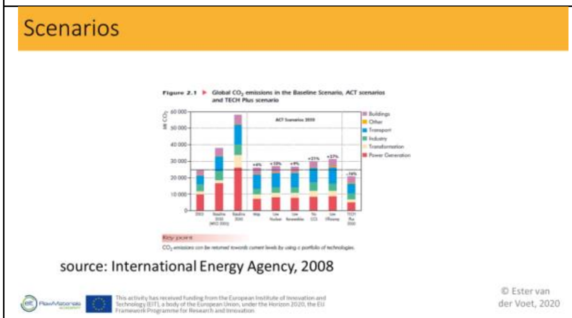
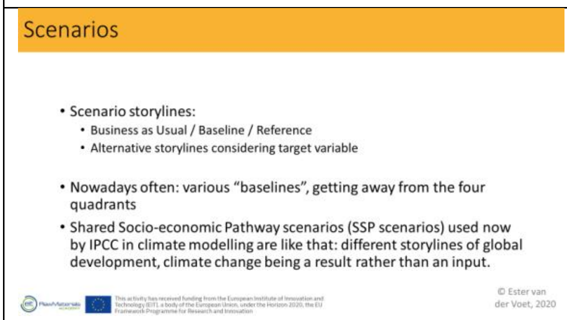


More examples, note the funny names used to characterise the scenarios. Again helpful for visualisation.



Scenarios for raw materials, or materials in general, do not yet exist. Some first attempts have been made by the International Resource Panel and the OECD (see Additional reading materials). These are quite preliminary and to date (2020) only include a baseline scenario. The baseline for raw materials is already challenging at global level. The three challenges mentioned here may be

	different for each specific raw material.
	This is the past: a powerful rise in iron ore production during the last decades. Though not so fast, this rise is expected to continue well into the future.
	This slide shows how environmental impacts are related to primary material production. Aluminium shows more differentiation in the developments of the impacts than iron. The reason is the changes (improvements) that have been implemented in the aluminium production processes. For iron and steel, the processes have not changed so much.
	This slide summarises the earlier ones and suggests to use the experience already available from the climate change scenario assessments.
	The previous slide also points at some differences. While for the climate scenarios the focus has to be on the impacts and the 2 degrees target, this is different for raw materials scenarios. There is no target, neither is it easy to imagine how one could arrive at such a target.
	Raw materials scenarios are much more like energy scenarios: there are no targets for the use of energy, only for the consequences of energy use, i.e. climate change. Resource scenarios could be constructed like energy scenarios, starting out from a demand projection, and then specifying a “mix” of different production routes. This is done for example in the World Energy Outlook scenarios

	of the International Energy Agency. For energy the mix refers to the energy technologies that can be employed. For resources, we still have to think about the rationale. This thought process has barely started yet, but it is becoming clear that secondary supply in the future has to play a much more important role.
 	Some IEA scenarios for energy use On this slide, the demand is shown for different world regions. It shows that OECD countries are responsible for about half the demand now, but in future other world regions will become more important while energy use in OECD countries stabilises. Could be detailed much further – information is available.
 	This slide then shows a variety of energy technology mixes, the different supply scenarios belonging to the demand scenarios.
 	..and this slide then shows the resulting CO2 emissions …. … that can then be translated into temperature rise with global climate models.
 	Introduction of the SSP scenarios as being different from the scenario modelling so far. The storyline does not refer to climate change but to general socio-economic developments. In that sense, all SSP scenarios are baselines. All SSP scenarios also have a 2 degree variant, employing different energy systems to supply the demand.

Scenarios • Scenario modelling is the next step • Very important (and especially for CRMs): make a difference between modelling demand and supply! 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 © Ester van der Voet, 2020	This point is really important and though quite simple apparently not self-evident. Even at global level, where it can be maintained (roughly) that supply equals demand, it is still very important to distinguish the two. Supply scenarios specify the “mix” of the different supply routes. Supply scenarios therefore are the entrance point for environmental assessments. They are also relevant for scenarios of the circular economy. A circular economy does not imply the demand is reduced, just that the supply is secondary supply for a considerable part.

Scenarios
Modelling demand:
• Two possible approaches: “top-down” and “bottom-up”
• Top down demand modelling:
  • using time series information of resource demand, and of relevant driving forces
  • comprehensive
  • enables linking with economic (CGE) models
  • flow-based, Input Output tables as main resource module
  • used by OECD in their energy scenarios and also in their resource scenarios (tbp)
  • suitable for BAU, difficult for non-trend scenarios
  • often lacking in detail, not suitable for CRMs
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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	We see two different approaches emerging now for resource scenarios: top-down and bottom-up. The top-down approach originates in macro-economic analysis and often uses CGE models. Economists think such modelling is the main, or even the only, way to go. The bottom-up approach originates from engineering and starts out from technologies and individual products. Engineers think such modelling is the main, or even the only, way to go. In fact, both have their strong points as well as their limitations, and we need elements of both to compile meaningful scenarios for resources.

Scenarios
Modelling demand (continued)
• Bottom up demand modelling:
  • building it up from most detailed level of resource applications and using driving force variables to forecast these applications
  • captures essential stock dynamics
  • enables including CRM and other minor materials
  • used by PBL in their IMAGE-TIMER models to forecast energy systems
  • suitable for non-trend scenarios
  • stock-based, dynamic Material Flow Analysis, Life Cycle Assessment
  • data intensive, database quite incomplete
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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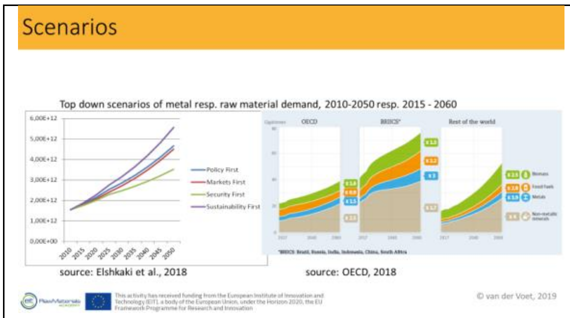
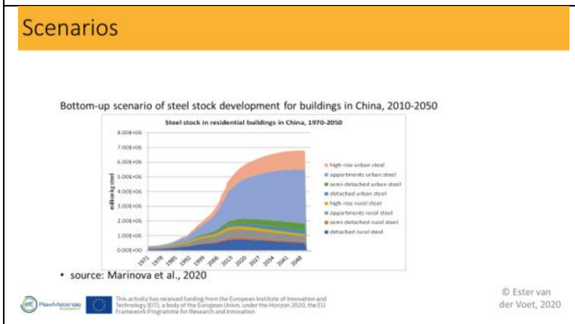
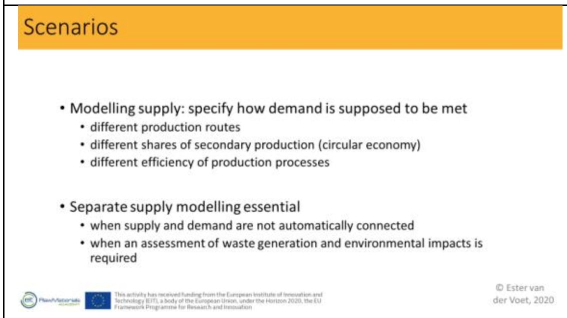
	CRM are only visible in a bottom-up approach. A top-down approach is too crude to enable following small-scale materials. It is however possible to take a bottom-up approach also with global level IAMs, as the examples from Deetman et al. and Marinova et al. show (see further slides).



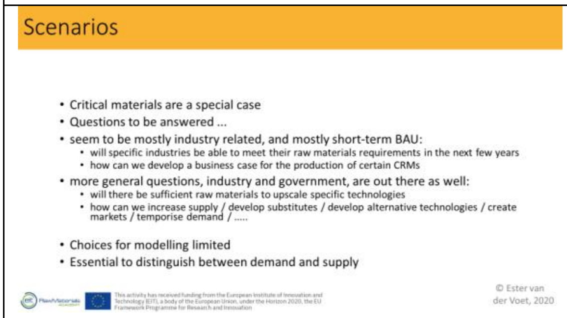
This is a top-down approach using only GDP and population as driving forces. Such an approach can, as can be seen here, also be used at the level of individual materials. For CRM it doesn't work so well as a (cor)relation between such drivers and the production of these materials cannot be established. This approach is taken by OECD in their resource scenarios, and also by the International Resource Panel in their Global Resources Outlook (IRP, 2019). Both these global level efforts are not relevant for CRM.



An example of bottom-up modelling of construction materials. This example refers to China but in fact these results exist for all 26 global IMAGE regions (IMAGE being one of the major climate models used for the IPCC assessments).



The relevant point here is that for CRM, as these are often co- of by-products of other materials, there is no automatic connection between supply and demand. Their supply depends on the demand for the "host" material.



CRMs are particularly difficult to capture in long-term forecasts. They are mostly new markets and suffer under supply constraints. If for example as a result of the increase in renewable energy technologies the demand for these materials would explode, it may not be possible to raise supply accordingly. In that case it is likely that the application will not persist and different technologies will be developed. That makes it very difficult and also rather irrelevant to try and compose a "baseline" scenario for these materials

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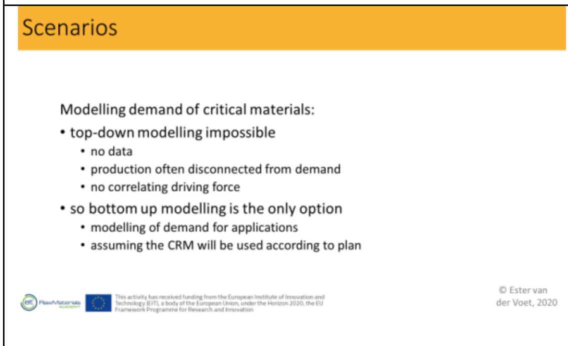
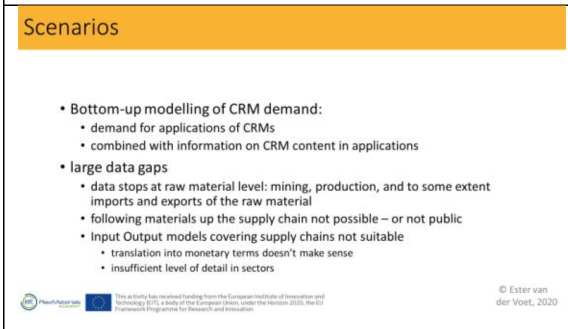
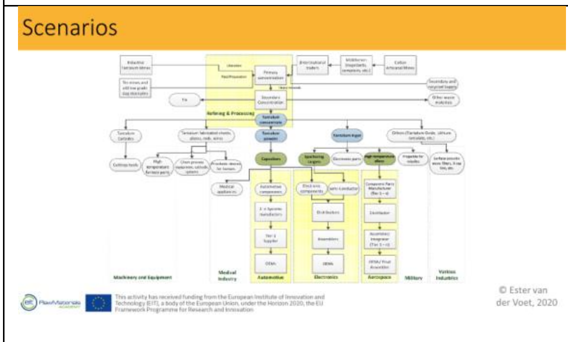
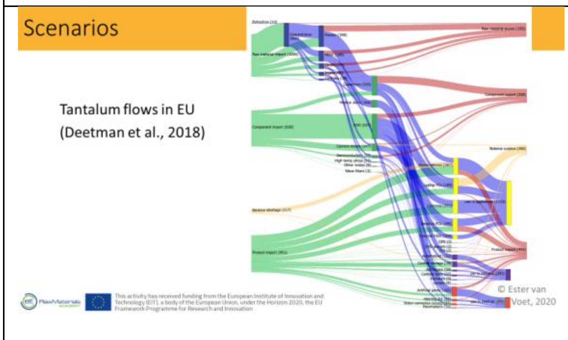
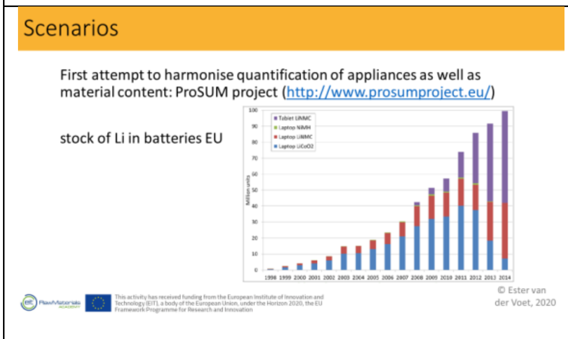
<tr><td>
</td><td>Modelling of applications of CRM is done and some examples are shown below. Such modelling assumes technologies will remain as they are now. This is most probably not a true assumption, but it is also very difficult to make a different assumption as it is quite uncertain or even unknown what will be the replacement.</td></tr>
<tr><td>
</td><td>In Input Output modelling, attempts are being made to include materials. This may be feasible for large-scale materials such as concrete or steel. It is futile for CRMs.</td></tr>
<tr><td>
</td><td>Deetman et al. (2018) have shown what happens if an attempt is made to construct a material flow account for Tantalum in the EU, based on the EXIOBASE input-output classification. They managed to construct such an account, but the input-output classification, although already quite detailed, was useless for following Tantalum flows.</td></tr>
<tr><td>
</td><td>An interesting side-result from this endeavour was, by the way, that there seem to be huge discrepancies in the global tantalum trade data. Trade flows of the raw material are huge compared to extraction data. Missing extraction data from some African countries is expected to be the cause of that.</td></tr>
<tr><td>
</td><td>The EU H2020 ProSUM project has done groundbreaking work in the classification of appliances to a level that is sufficienty detailed to enable assessing CRMs. They have applied their approach on electronic devices, on passenger cars and on batteries, for the EU and all its member states. Results can be found on their website.</td></tr>
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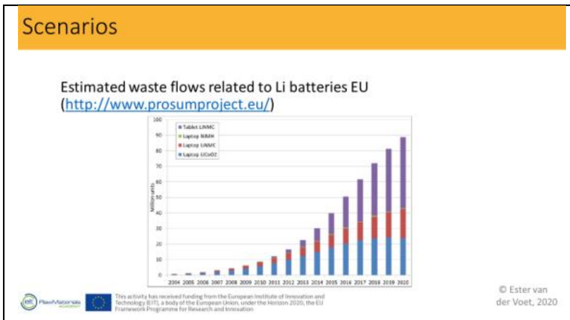

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<td>Production, trade, consumption and waste flows are assessed in the ProSUM project, at the product level but also at the element level.</td>
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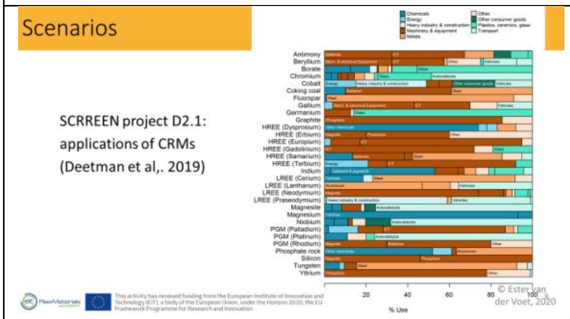

</td>
<td>Another project that has looked into CRMs is SCRREEN, another EU Horizon 2020 project. They have made an inventory of present applications of CRM, and starting from there have looked into the future.</td>
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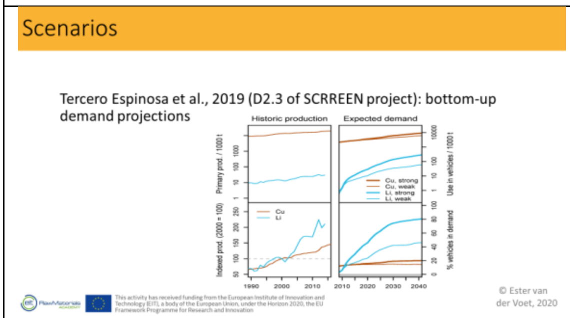

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<td>Projections into the future have been based mostly on the expectations around the technologies that these CRM are used in.</td>
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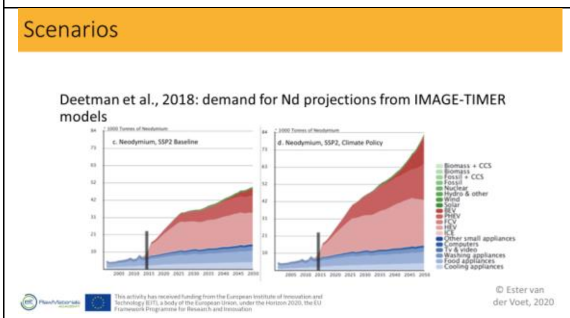

</td>
<td>This is another example of CRM scenarios, related to the IMAGE model and the quite detailed scenario information about energy and mobility technologies. Again, alas, no changes assumed in technology until 2050. In that sense this scenario (actually, the SSP2 scenario, baseline and 2 degrees) is not “realistic”. It does show, however, a huge increase in demand (in this case, of Neodymium, but the assessment has been made for a number of other materials as well) and can thus be input for decision making on whether or not to diversify technology or develop CRM free technology.</td>
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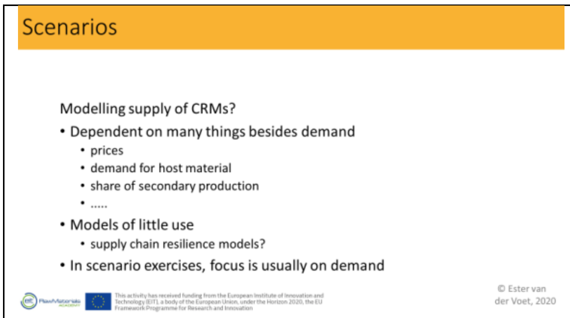
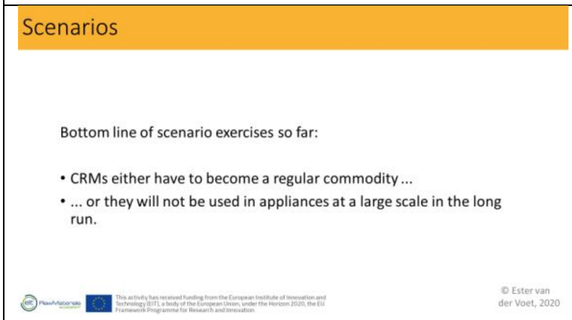
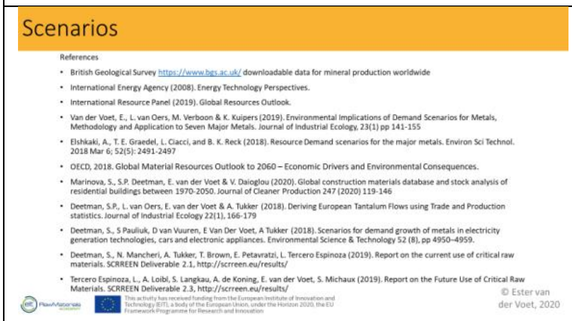
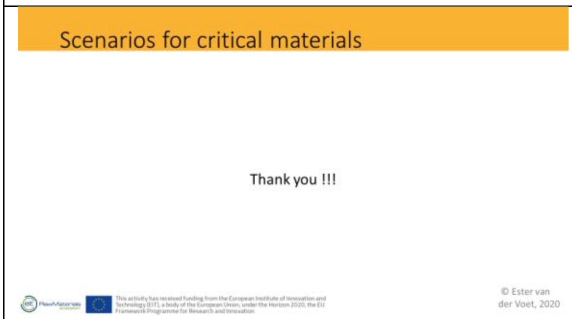




This is a personal observation of the author of these slides. It seems a logical conclusion from the fact that the demand under unchanging technology assumptions will rise so dramatically, and supply almost certainly will not be able to keep up. Feel free to omit this slide if disagreed.





Scenarios for critical raw materials: the case of Cobalt

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<td>The first 13 slides contain material also shown in the Scenarios for raw materials lecture.</td>
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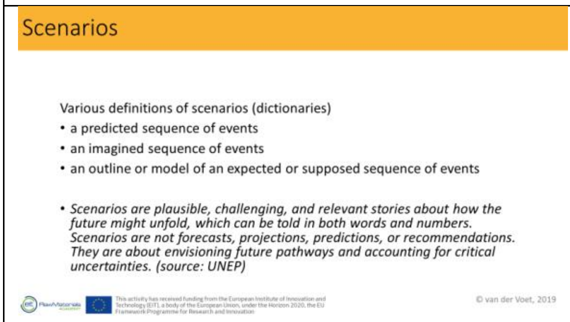
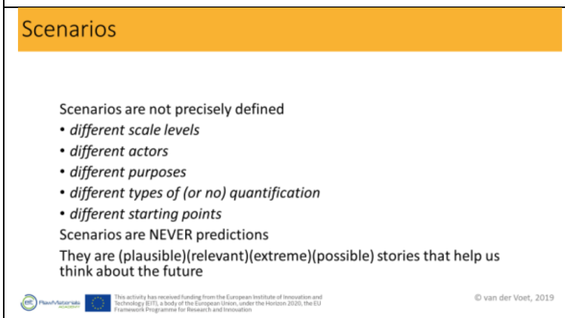
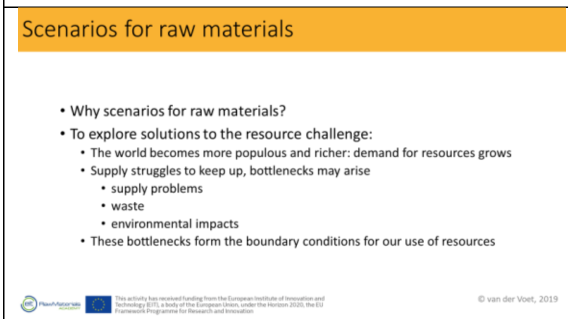
<tr>
<td>
</td>
<td>Make clear scenarios are NOT predictions, despite what the dictionaries say. Scenarios are about the future, and therefore by definition inaccurate. We use the UNEP definition.</td>
</tr>
<tr>
<td>
</td>
<td>To illustrate the breadth of the concept of scenario analysis</td>
</tr>
<tr>
<td>
</td>
<td>Scenarios for raw materials, or materials in general, do not yet exist. Some first attempts have been made by the International Resource Panel and the OECD (see Additional reading materials). These are quite preliminary and to date (2020) only include a baseline scenario. The baseline for raw materials is already challenging at global level. The three challenges mentioned here may be different for each specific raw material.</td>
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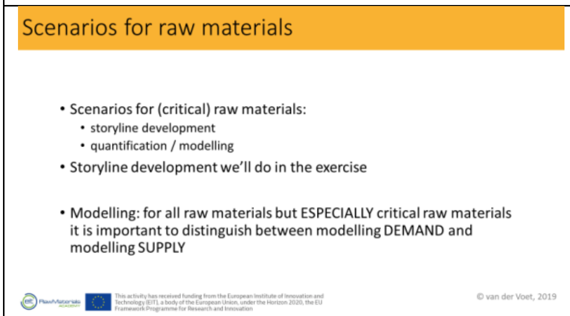
<td>
</td>
<td>This point is really important and though quite simple apparently not self-evident. Even at global level, where it can be maintained (roughly) that supply equals demand, it is still very important to distinguish the two. Supply scenarios specify the "mix" of the different supply routes. Supply scenarios therefore are the entrance point for environmental assessments. They are also relevant for scenarios of the circular economy. A circular economy does not imply the demand is reduced, just that the supply is secondary supply for a considerable part. In addition, for critical raw materials, there is often a disconnection between supply and demand, since these materials are often produced as co- or by-products of other materials.</td>
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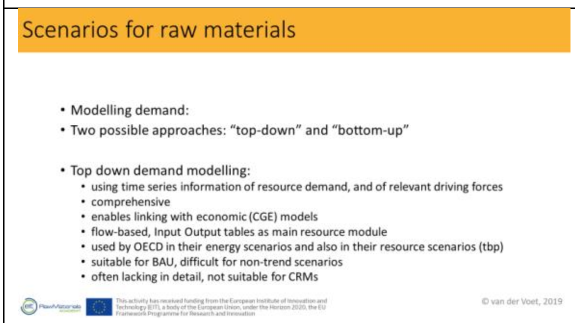
<td>
</td>
<td>We see two different approaches emerging now for resource scenarios: top-down and bottom-up. The top-down approach originates in macro-economic analysis and often uses CGE models. Economists think such modelling is the main, or even the only, way to go. The bottom-up approach originates from engineering and starts out from technologies and individual products. Engineers think such modelling is the main, or even the only, way to go. In fact, both have their strong points as well as their limitations, and we need elements of both to compile meaningful scenarios for resources.</td>
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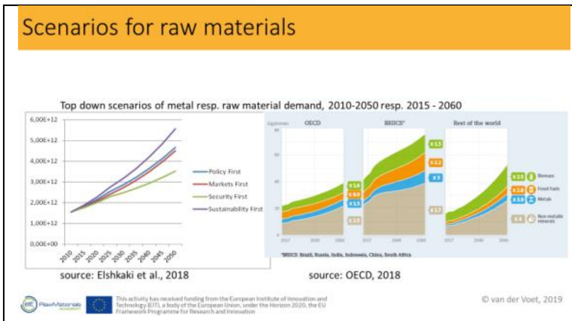
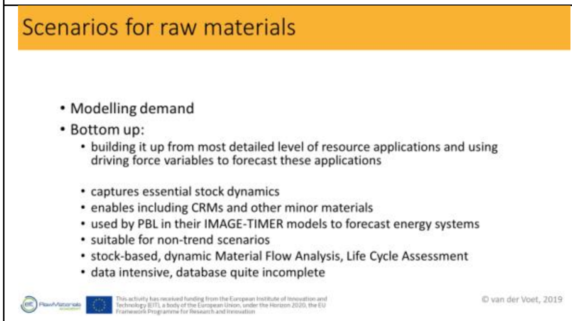
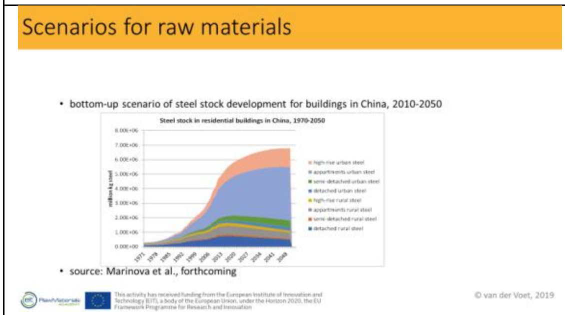


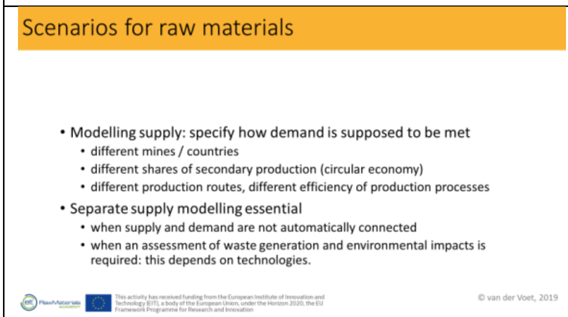
This is a top-down approach using only GDP and population as driving forces. Such an approach can, as can be seen here, also be used at the level of individual materials. For CRM it doesn't work so well as a (cor)relation between such drivers and the production of these materials cannot be established.



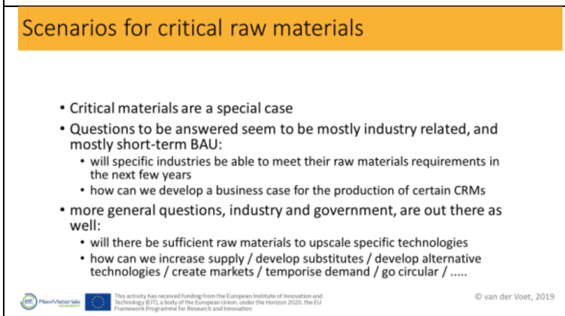
CRM are only visible in a bottom-up approach. A top-down approach is too crude to enable following small-scale materials. It is however possible to take a bottom-up approach also with global level IAMs, as the examples from Deetman et al. and Marinova et al. show (see further slides).



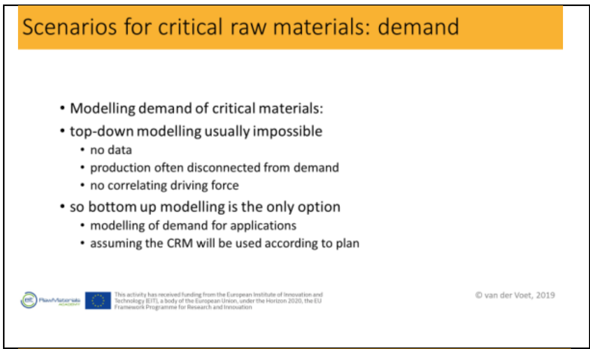
An example of bottom-up modelling of construction materials. This example refers to China but in fact these results exist for all 26 global IMAGE regions (IMAGE being one of the major climate models used for the IPCC assessments).



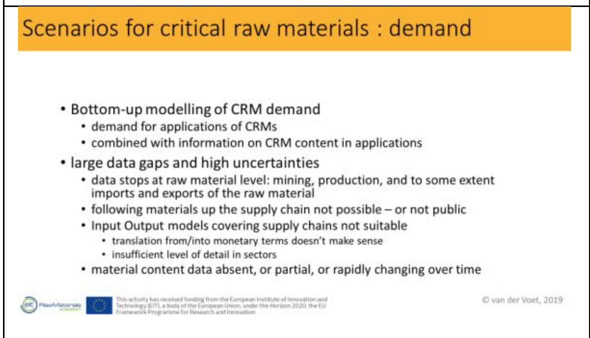
The relevant point here is that for CRM, as these are often co- of by-products of other materials, there is no automatic connection between supply and demand. Their supply depends on the demand for the "host" material.



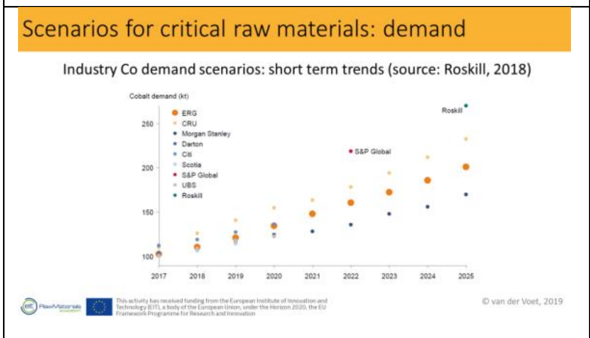
CRMs are particularly difficult to capture in long-term forecasts. They are mostly new markets and suffer under supply constraints. If for example as a result of the increase in renewable energy technologies the demand for these materials would explode, it may not be possible to raise supply accordingly. In that case it is likely that the application will not persist and different technologies will be developed.



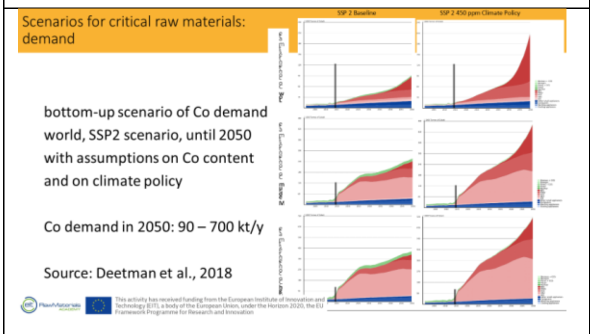
Modelling of applications of CRM is done and some examples are shown below. Such modelling assumes technologies will remain as they are now. This is most probably not a true assumption, but it is also very difficult to make a different assumption as it is quite uncertain or even unknown what will be the replacement.



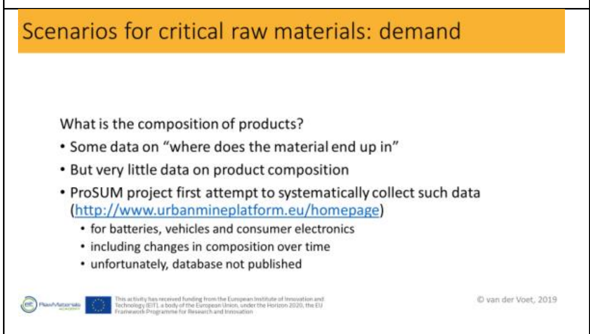
In Input Output modelling, attempts are being made to include materials. This may be feasible for large-scale materials such as concrete or steel. It is futile for CRMs.



Here starts the new material, with some specific demand scenarios for cobalt. This one from the industry – only until 2025.

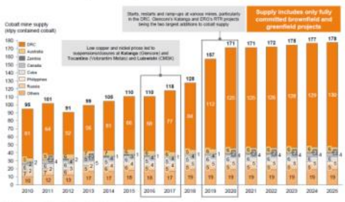
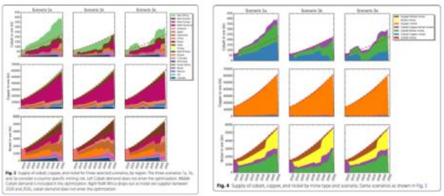


This scenario is also shown in the slides of the general Raw materials scenarios lecture. It refers to cobalt and shows results until 2050, under assumptions of constant technology.



ProSUM is really a very relevant project and presents lots of materials that can be used for a bottom-up scenario development for CRM.

Scenarios for critical raw materials: supply
 	
• Modelling supply of CRMs?
• Dependent on many things besides demand
  • prices
  • demand for host material
  • share of secondary production
  • .....
• Models of little use
  • supply chain resilience models?
• Some estimates for the short term based on present situation
• In scenario exercises, focus is usually on demand
 	
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
© van der Voet, 2019
	It is even more difficult to forecast supply as there are many unknowns. For CRMs, supply = demand is way too simplistic.

Scenarios for critical raw materials: supply • supply scenario for Co (Roskill, 2018)  © van der Voet, 2019	Supply projections only cover very short periods and depend on present mining operations only.
Scenarios for critical raw materials: supply • supply scenario for Co (Tisserant & Pauliuk, 2016)  © van der Voet, 2019	This shows results from a bold scenario attempt for cobalt supply scenarios until 2050. Various eventualities have been explored here.
References • OECD, 2018: Global Material Resources Outlook to 2060 – Economic Drivers and Environmental Consequences (highlights brochure) • Elshkaki et al., 2018: *Environ Sci Technol.* **2018** *52* (5), 2491-2497 • Roskill, 2018: Presentation Battery Supply Chain Europe 2018 • Deetman et al, 2018: *Environ Sci Technol.* **2018** *52*(8):4950-4959 • Tisserant & Pauliuk, 2016: Economic Structures (2016) 5: 4. https://doi.org/10.1186/s40008-016-0035-x © van der Voet, 2019	
Scenarios for critical raw materials: exercise Exercise Scenarios for cobalt: *Develop with your group a **storyline** for future cobalt demand and supply* *Make an assessment of cobalt demand and supply under this scenario* *Identify problematic issues and speculate on whether these could be solved* *Don't worry about being accurate or realistic, this is NOT the purpose of this exercise* *See hand-outs!* © van der Voet, 2019	The explanation of the scenario exercise can be found in the hand-out: the Word document called Scenario Storyline Development Exercise.

Scenarios for critical raw materials There are four different types of scenarios (each group selects one via the envelope): • rapid energy transition scenario • circular economy scenario • strict sourcing policies scenario • black swan (some disaster happens) Scale is global, time horizon is up to 2050 A business-as-usual is provided, see handout, to use as a reference. © van der Voet, 2019	The envelope: little slips of paper with the scenario titles on them are folded and put into an envelope, to be drawn by the different groups like lots.
Scenarios for critical raw materials Step 1. specify the "background" system for your scenario • socio-economic developments (population, welfare) • technology developments • (geo)political developments • other relevant developments Pay special attention to deviations from trends. © van der Voet, 2019	A step-by-step approach is introduced. Checking back after each step is recommended, especially for groups that are not used to these brainstorming type exercises. Frequent reassurances that there is no need to be realistic or accurate are recommended as well. It is all about the thought experiment.
Scenarios for critical raw materials Step 2. Specify demand (bottom-up) • how will demand for Co containing applications develop in your scenario • just relative trends is good enough: more / less than BAU • drops or surges are especially interesting © van der Voet, 2019	
Scenarios for critical raw materials Step 3. Speculate on consequences. You can use all information you have obtained in this course, or any other, or none, to support you • are supply bottlenecks to be expected, and could something be done about that • what are consequences for society at large © van der Voet, 2019	
Scenarios for critical raw materials Step 4. Visualise: draft 1 figure to characterise your scenario Think of a name for your scenario Include demand and supply development for cobalt in this figure Step 5: present your scenario in 1 minute © van der Voet, 2019	Usually this is a timeline where demand and supply of cobalt are drafted.

Cobalt and Lithium: Potential Supply from the Urban Mine

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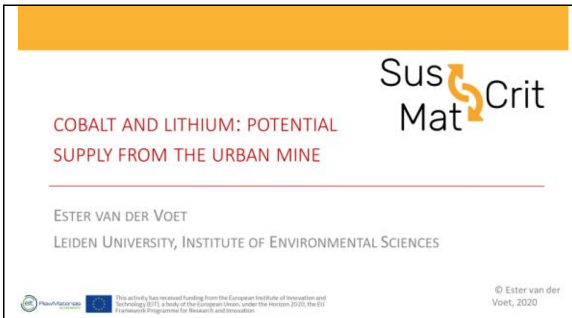
<td>
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<td>One of the potential ways out of the ever increasing need to boost supply is to move towards a circular economy and start urban mining. There is a separate teaching package on urban mining for an understanding of that concept.
In this presentation we focus on Li and Co.</td>
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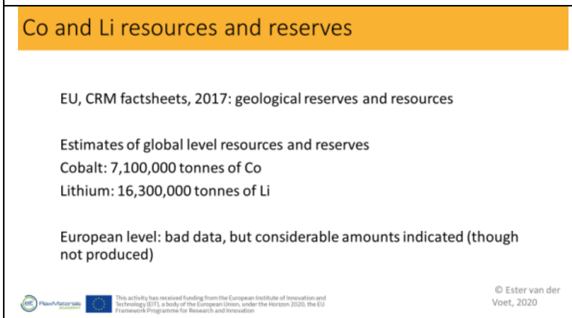
<td>
</td>
<td>A tour through the data base for these two raw materials at these three scale levels.</td>
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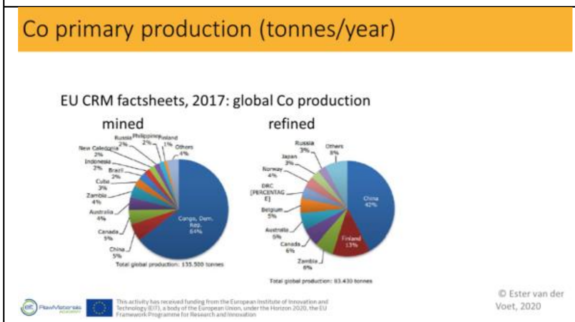
<td>
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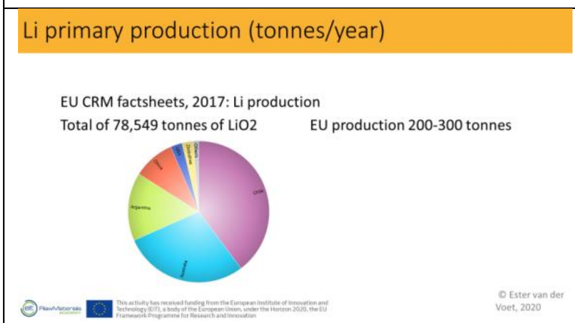
<td>
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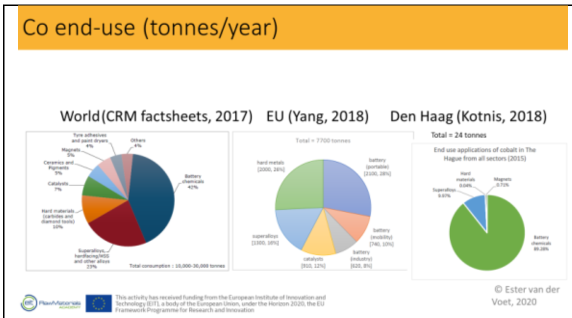
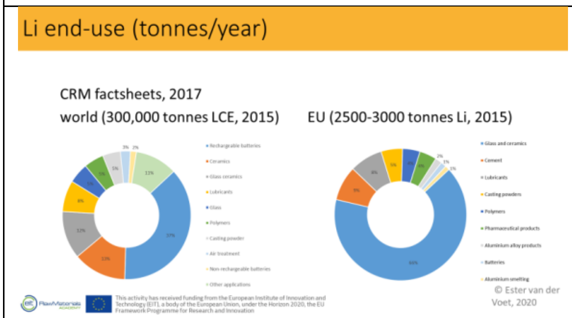
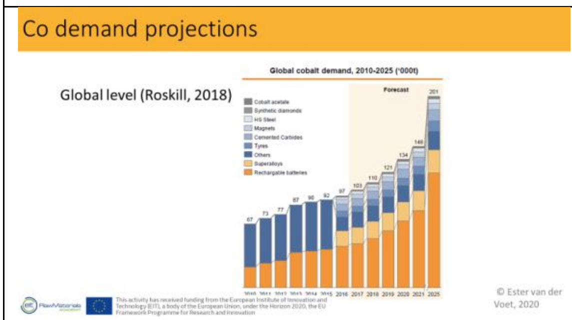
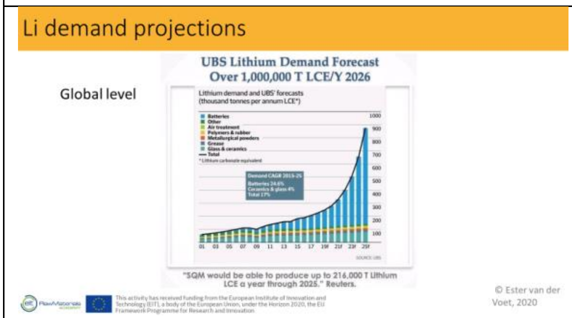
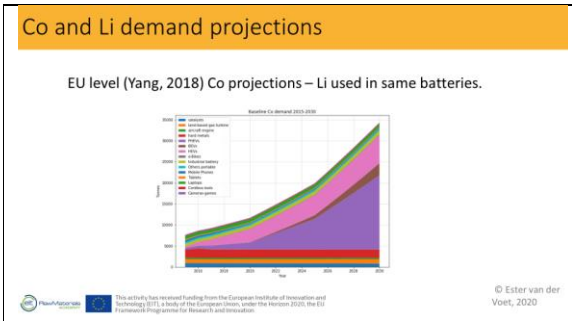
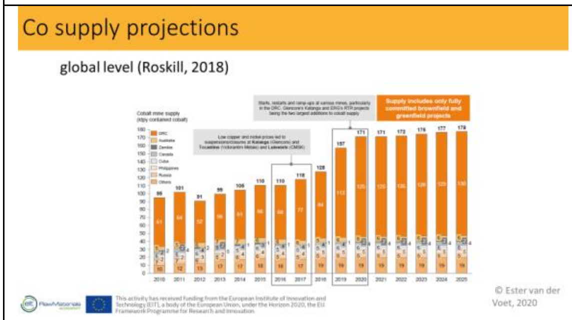
	The figures show the different uses of cobalt at the three scale levels. The differences between global and EU level probably have to do with the different economic systems – industrial structures as well as the employment of certain products. At the local level of The Hague there is hardly any industry, therefore, industrial uses are absent. Also, at the local level there is a lack of data and this graph is the result of known end-uses of consumers and assumptions on the cobalt content of these end-uses. Yang and Kotnis are Master students who did their Master thesis research on cobalt in the EU resp. in the Dutch city of Den Haag (The Hague).
	Similar information for lithium. Here, the local level is missing.
	Demand projections for Cobalt only for the VERY near future. Already here we can see an expected rapid rise.
	And the same for Lithium.

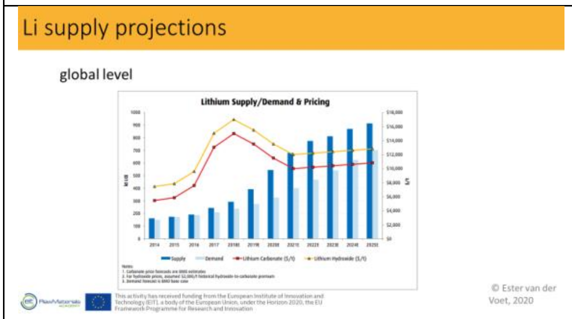


Student research can be a bit bolder in extending the time horizon. Yang shows demand projections for cobalt until 2030, with a rapid rise especially of Co-application in batteries. Lithium is used in those same batteries, so a similar rise can be expected for Li as well.

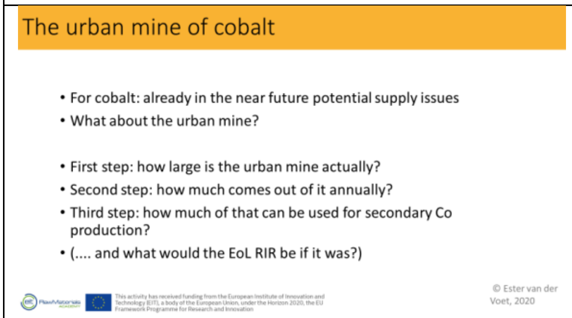


Supply projections even for the shorter term, based on present mining endeavours and present knowledge only.

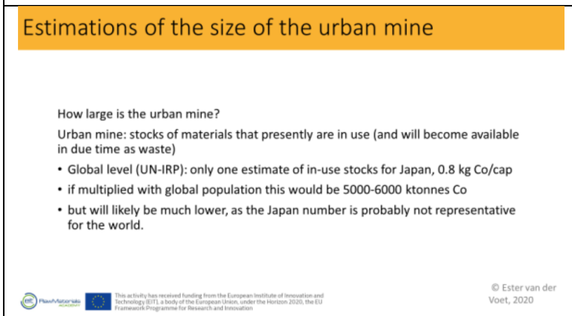
Comparing supply and demand projections indicate there may be a problem for Cobalt already in the near future.



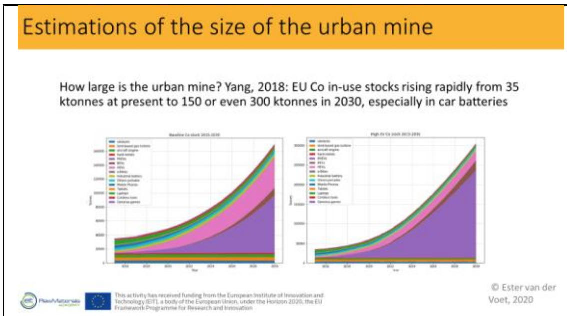
For lithium, the situation is different. Here we see a supply that is larger than the demand, also expected for the (near) future. This already has an impact on Li prices.



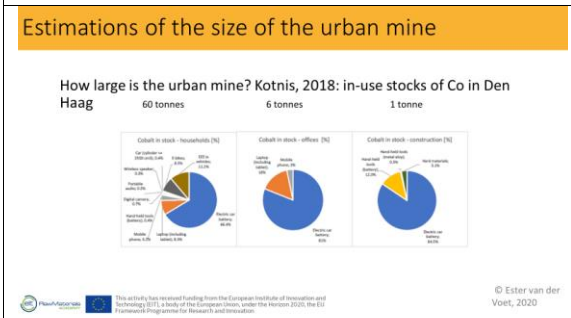
Can the urban mine be a solution? That exploration needs various steps.



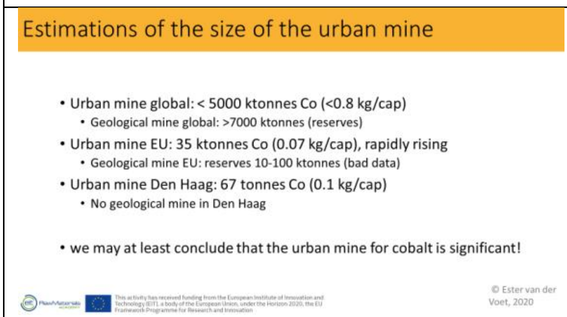
Exploration of the existing information on the urban mine, i.e. the presently used applications in the in-use stock in society. Again at the three scale levels. In this slide, the scarce information at global level is presented. The main source is the report from 2010 on stocks in society published by the International Resource Panel, a first comprehensive attempt to quantify in-use stocks for a broad array of elements.



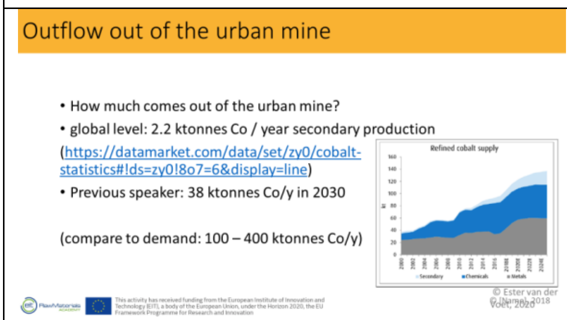
This is assuming there will not be any supply restrictions, and also assuming the cobalt content of the applications will not change. Those are most likely both untrue assumptions, but making more sophisticated assumptions is very difficult.



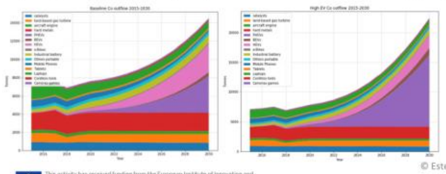
Kotnis' main focus was to estimate the in-use stock of cobalt. She used information on the use of household and office appliances and the associated carbon contents, as well as cobalt in steel used for construction.



These rough numbers show at least that the urban mine may be in the same order of magnitude as the geological mine. From this investigation it may also be suspected that the per capita cobalt use is rather in the 0.1 kg/cap order than in the 0.8 kg/cap order, as following from the estimate for Japan.

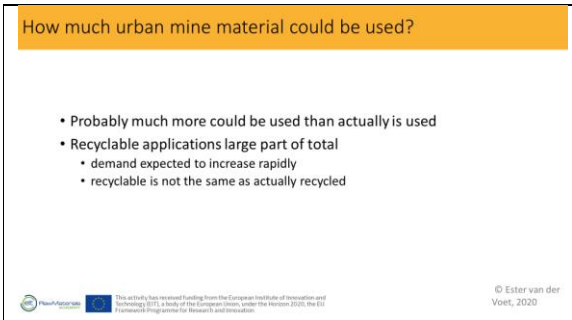
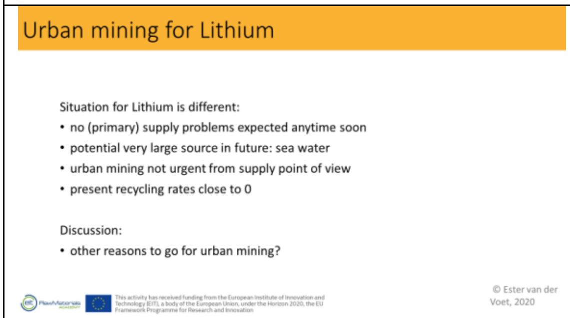
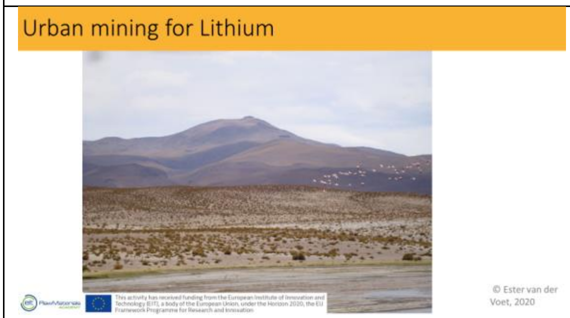
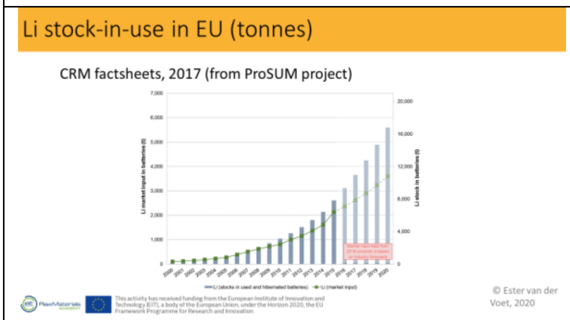


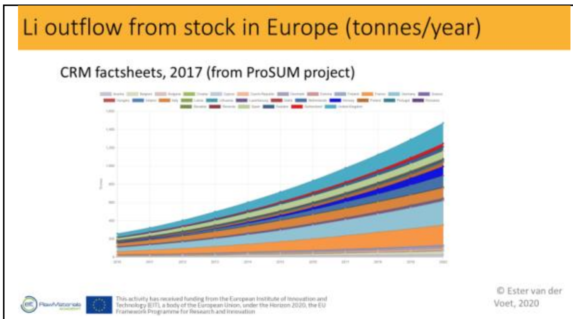
What is in stock, is the magnitude of the urban mine. However contrary to geological mines, additional information is needed on to what extent the urban mine can be exploited. The material is, after all, in use. So, what we can expect to come out of the urban mine, to be available for secondary production? Again the three scale levels, and the global level on this slide. At global level, the scarce information indicates that secondary production presently is very small compared to demand.

Outflow out of the urban mine • Yang, 2018: outflow out of urban mine presently 7 ktonnes Co/year in EU, rising to 15-22 in 2030 (compare to demand: 35 ktonnes Co/year)  © Ester van der Voet, 2020	At EU level, the amount of cobalt presently coming out of the urban mine is 7 ktonnes, more than secondary production at world scale. Note that the outflow from the urban mine is not the same as secondary production. What happens to the outflow is not very well known, but it is quite possible that most of it ends up in waste streams from which Co is not retrieved.
Outflow out of the urban mine • Kotnis, 2018: presently 8 tonnes Co/year flows out of the urban mine of Den Haag © Ester van der Voet, 2020	And here the same observation: this number does not tell us what happens to the waste, and probably very little of it is recycled right now.

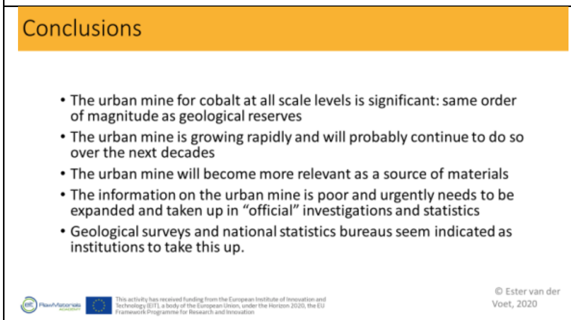
How much urban mine material is used?
• Present recycling rates, global level:
  • UN-IRP: EoL RR of 68%, RC 32% (but data for USA only)
  • Hamilton, 2017: RC presently a few % at global level
• Very uncertain, very different estimates
• Large data gaps
© Ester van der Voet, 2020
	Next question: how much of what flows out of the urban mine is, or can be, used? Very uncertain and contradictory information at all scale levels. The recycling rates at global level are presented here. Note that the estimates differ from a few percent to two thirds. The high percentages refer to the USA so are probably not representative of what happens in the world. The estimate of Hamilton refers to the Recycled Content: the fraction of supply that comes from recycling. Whereas the End of Life Recycling rate refers to the fraction of waste that is being recycled. This is not the same.

How much urban mine material is used? • EU: EoL RIR = 0% (CRM factsheets 2017) • EU: EoL RIR = 35% (EC Report CRMs and the Circular Economy) • Den Haag: unknown! © Ester van der Voet, 2020	For the EU, there are also two widely different estimates. Both refer to the End of Life Recycling INPUT Rate, which is similar to the Recycled Content, the fraction of supply that comes from recycling. The main conclusion to be drawn here is that there is too little information. For The Hague, there is no number at all.

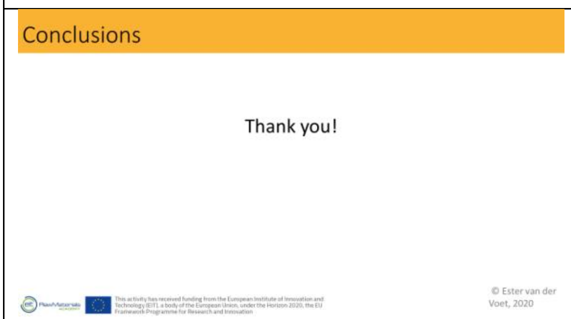
	Technically it is probably possible to increase EoL recycling rates, as the recyclable applications form a large part of the total.
	The incentive to start mining the urban mine for lithium is very low, as in the present there is already an oversupply situation and prices are dropping. There may, however, be other reasons to prefer the urban mine over primary production. For example, environmental reasons.
	This picture shows the salar near Uyuni, a small town in the Andes mountains in Bolivia. It is presently a quiet and remote area, difficult to go to, and part of a fragile and valuable ecosystem. This location is considered as a potential source of large scale lithium production.
	Exploiting the salars would imply a lot of changes: roads and other infrastructure has to be built, production plants have to be constructed, towns have to be built or expanded. This would probably mean the end of these ecosystems – here, a flock of flamingos can be seen that breed in these remote areas. Avoiding such destruction could be another reason to shift attention to urban mining.
	In the ProSUM project, some (short-term) estimates are made of the urban mine for EU and member states.



This figure also is a result of the ProSUM investigations: the outflow out of the in-use stock, also for the very near future, can be seen to rapidly rise. For the more distant future, it is difficult to find information at present.



Preliminary conclusions: for supply security as well as environmental reasons it is worthwhile to start exploring the possibilities for urban mining. Information on the urban mine is scarce at the moment. Probably the most relevant actors to host the information base for the urban mine are the geological surveys, that already have the information on geological stocks. Statistical offices could be indicated to keep track of waste streams, trade and recycling. If we want to move towards a circular economy, it is essential to strengthen the database on the mines of the future.



3 Exercises

The exercise of this module is related to storyline development for critical raw materials, more specifically for cobalt. The hand-out (Word document, Scenario Storyline development exercise) contains all the information necessary, which is mainly the uses of cobalt and one forecast of cobalt that can serve as a baseline against which to offset the other scenarios. The aim is not to model or quantify, but to indicate the direction of developments compared to this baseline.

The exercise is done in groups (4-7 people), that each have to develop one scenario. The scenarios are distributed by fate over the groups. They are the following:

- rapid energy transition scenario (which may increase demand)
- circular economy scenario (which may increase secondary supply)
- strict sourcing policies scenario (which may put some mines out of operation)
- black swan scenario (which can be anything, as long as its impacts on cobalt supply and/or demand are dramatic).

More than four groups? No problem thinking about additional titles yourself, or having two groups per scenario. Groups are guided through the whole process by doing the exercise one step at a time. The main purpose of the exercise is to start the thought process about what influences demand and supply, and what are consequences of demand or supply changes. Because the time horizon is set so far into the future, groups are encouraged to think out-of-the-box and are not constrained too much by the present situation and the very short term considerations usually dominant in the CRM debate.

4 Acknowledgements and Authors

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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:

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Patrick Wäger, Empa
Steven Young, University of Waterloo

Besides, many others invested their time and expertise to discuss and review the teaching materials.

5 Citation

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6 Disclaimer

The teaching materials within the SusCritMat project have been prepared with great care and experienced several revisions. Nevertheless, the consortium assumes no liability for the topicality, completeness and correctness of the content provided.

In case you have suggestions or other feedback how to improve the materials, we value your opinion: Please contact us via the project webpage https://suscritmat.eu/contact/.