

Teaching Resources on the Sustainable Management of Critical Raw Materials

Trainer's Manual for Metals and Critical Raw Materials Scenarios

March 2020

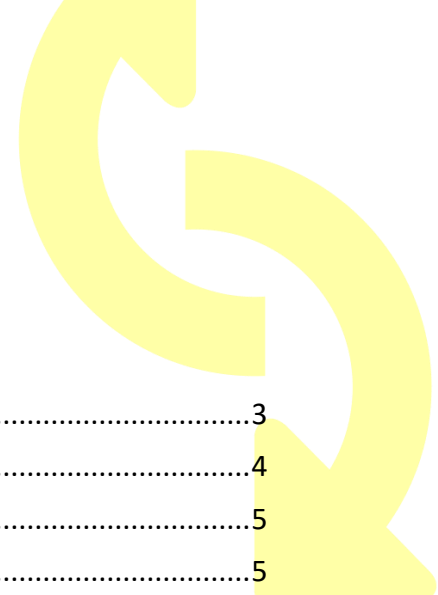


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1 Context and Introduction to Training

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.

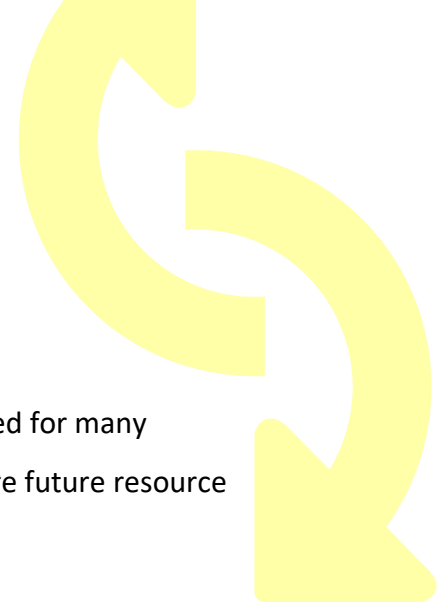
SusCritMat is an EU-funded project that brings together the technical and pedagogical expertise of leading educational institutions and business partners. It uses and creates teaching materials which can be combined into different course formats.

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.

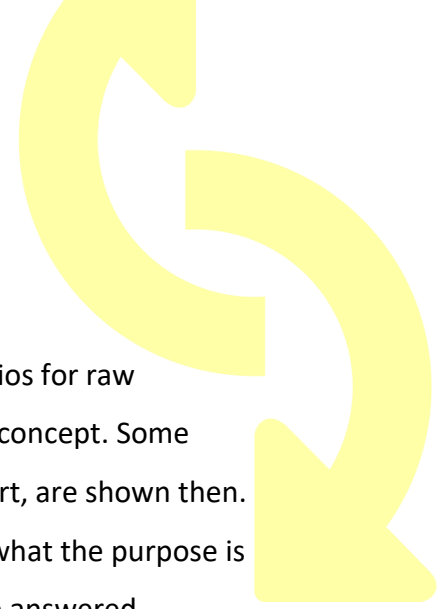
1.4 Learning Objectives for the scenarios module

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).

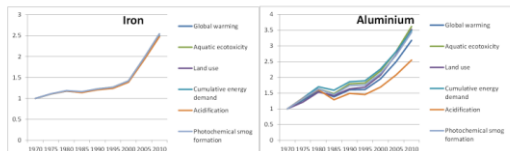
The **third set of slides** is on the urban mine of cobalt and lithium. In a circular economy, society's material basis will be the urban mine. Presently there is very little insight in the magnitude of the urban mine, for these and other materials. The slides contain a first exploration of whether or 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.

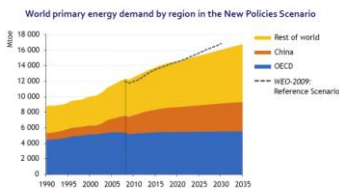
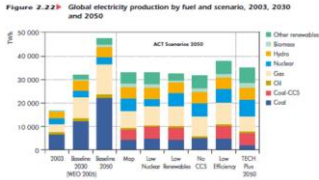
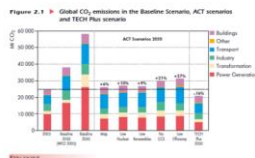
Slides for Scenarios for Critical Raw Materials




 <p>SCENARIOS FOR CRITICAL RAW MATERIALS</p> <p>ESTER VAN DER VOET LEIDEN UNIVERSITY, INSTITUTE OF ENVIRONMENTAL SCIENCES</p> <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	
<p>Contents of lecture</p> <ul style="list-style-type: none"> • Scenarios • Scenarios for raw materials • Scenarios for critical raw materials <ul style="list-style-type: none"> • Demand scenarios • Supply scenarios • Some observations <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	
<p>Scenarios</p> <p>Various definitions of scenarios (from dictionaries)</p> <ul style="list-style-type: none"> • a predicted sequence of events • an imagined sequence of events • an outline or model of an expected or supposed sequence of events <p><i>Scenarios are plausible, challenging, and relevant stories about how the future might unfold, which can be told in both words and numbers. Scenarios are not forecasts, projections, predictions, or recommendations. They are about envisioning future pathways and accounting for critical uncertainties. (source: UNEP)</i></p> <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<p>Scenarios</p> <p>Scenarios can be used to explore consequences of actions</p> <ul style="list-style-type: none"> • What happens if we do nothing? What challenges will we meet? • What will happen as a result of certain decisions? Does it solve the challenges? Might there be new challenges? <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<p>Scenarios</p> <ul style="list-style-type: none"> • To explore future possibilities we can define <ul style="list-style-type: none"> • A reference or baseline, often “business-as-usual” • A best and/or worst case • Other possible pathways, neutral or in between • Starting point can be <ul style="list-style-type: none"> • Present, exploring developments for the future (forecasting) • Future, making explicit what needs to be done (backcasting) <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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</p>

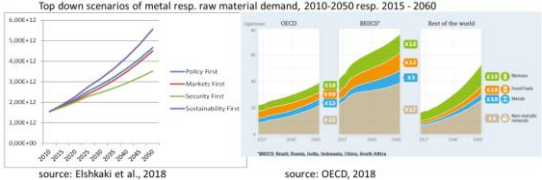



	<p>desired future – and explores pathways back to the present. Forecasting answers questions like: what would happen if ...? Backcasting answers questions like: what is needed to get where we would like to be?</p>
<p>Scenarios</p> <ul style="list-style-type: none"> Scenarios can be used at any scale level <ul style="list-style-type: none"> Personal: economic decisions at household level Local governments: development of neighbourhoods, decisions around construction activities Companies: to support decisions on large scale investments National governments: to support economic, social or environmental policies Continental and global level: to signal global challenges and constraints <p><small>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.</small></p> <p><small>© Ester van der Voet, 2020</small></p>	
<p>Scenarios</p> <ul style="list-style-type: none"> Scenarios for different questions <ul style="list-style-type: none"> Long-term vs. Short-term Baseline vs. Transition Quantitative vs. Qualitative Partial / local vs Comprehensive / global Forecasting vs. Backcasting Normative vs Exploratory <p><small>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.</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p> <p>Especially relevant to acknowledge that quantification is not always necessary: sometimes, the storyline may already be sufficient information.</p> <p>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.</p>
<p>Scenarios</p> <ul style="list-style-type: none"> Most experience with scenarios for climate change <p><small>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.</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>

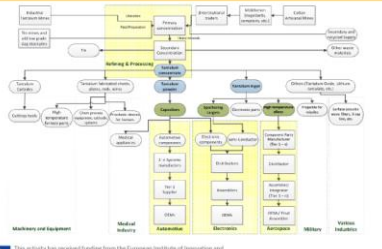
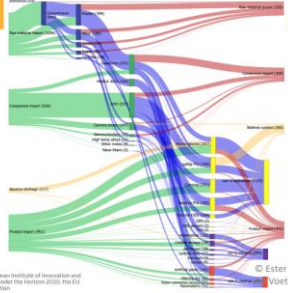
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	different for each specific raw material.								
<div>Scenarios</div> <div><p>source: British Geological Survey, 2018</p><p><small>This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation</small></p><p><small>© Ester van der Voet, 2020</small></p></div>	<p>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.</p>								
<div>Scenarios</div> <div><p>source: van der Voet et al., 2019</p><p><small>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</small></p><p><small>© Ester van der Voet, 2020</small></p></div>	<p>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.</p>								
<div>Scenarios</div> <div><ul style="list-style-type: none">Resource scenarios do not yet exist: how will / can / might future resource demand and supply develop?Many variables, to be explored in scenarios with different storylines<p><small>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</small></p><p><small>© Ester van der Voet, 2020</small></p></div>	<p>This slide summarises the earlier ones and suggests to use the experience already available from the climate change scenario assessments.</p>								
<div>Scenarios</div> <div><p>Resource scenarios could be limited to society</p><table><tr><th>Storylines</th><th>Socio-economic scenarios (demand)</th><th>Technology (supply)</th><th>Extractions and emissions (consequences)</th></tr><tr><td></td><td></td><td></td><td></td></tr></table><p><small>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</small></p><p><small>© Ester van der Voet, 2020</small></p></div>	Storylines	Socio-economic scenarios (demand)	Technology (supply)	Extractions and emissions (consequences)					<p>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.</p>
Storylines	Socio-economic scenarios (demand)	Technology (supply)	Extractions and emissions (consequences)						
<div>Scenarios</div> <div><p>Resource scenarios would be comparable to energy scenarios rather than climate scenarios</p><ul style="list-style-type: none">Not just energy demand, but also energy supply is specifiedFuel and electricity mixesSometimes quite detailed with regard to sector and world region<p>Energy scenarios:</p><ul style="list-style-type: none">IEA: WEO scenarios specified by Energy Technology Perspectives modelShell scenariosMainly technology oriented, mix between business-as-usual and meeting climate targets<p><small>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</small></p><p><small>© Ester van der Voet, 2020</small></p></div>	<p>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</p>								

	<p>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.</p>
<p>Scenarios</p>  <p>source: International Energy Agency, 2008</p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant.</small></p> <p>© Ester van der Voet, 2020</p>	<p>Some IEA scenarios for energy use</p> <p>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.</p>
<p>Scenarios</p>  <p>source: International Energy Agency, 2008</p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant.</small></p> <p>© Ester van der Voet, 2020</p>	<p>This slide then shows a variety of energy technology mixes, the different supply scenarios belonging to the demand scenarios.</p>
<p>Scenarios</p>  <p>source: International Energy Agency, 2008</p> <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant.</small></p> <p>© Ester van der Voet, 2020</p>	<p>..and this slide then shows the resulting CO2 emissions</p> <p>... that can then be translated into temperature rise with global climate models.</p>
<p>Scenarios</p> <ul style="list-style-type: none"> Scenario storylines: <ul style="list-style-type: none"> Business as Usual / Baseline / Reference Alternative storylines considering target variable Nowadays often: various "baselines", getting away from the four quadrants Shared Socio-economic Pathway scenarios (SSP scenarios) used now by IPCC in climate modelling are like that: different storylines of global development, climate change being a result rather than an input. <p><small>This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant.</small></p> <p>© Ester van der Voet, 2020</p>	<p>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.</p>

<p>Scenarios</p> <ul style="list-style-type: none"> • Scenario modelling is the next step • Very important (and especially for CRMs): make a difference between modelling demand and supply! <p><small>  This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodé Curie grant agreement. </small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<p>Scenarios</p> <p>Modelling demand:</p> <ul style="list-style-type: none"> • Two possible approaches: “top-down” and “bottom-up” • Top down demand modelling: <ul style="list-style-type: none"> • 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 <p><small>  This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodé Curie grant agreement. </small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<p>Scenarios</p> <p>Modelling demand (continued)</p> <ul style="list-style-type: none"> • Bottom up demand modelling: <ul style="list-style-type: none"> • 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 <p><small>  This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodé Curie grant agreement. </small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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).</p>


<p>Scenarios</p>  <p>Top down scenarios of metal resp. raw material demand, 2010-2050 resp. 2015 - 2060</p> <p>source: Elishaki et al., 2018</p> <p>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</p> <p>© Ester van der Voet, 2019</p>	<p>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.</p>
<p>Scenarios</p>  <p>Bottom-up scenario of steel stock development for buildings in China, 2010-2050</p> <p>source: Marinova et al., 2020</p> <p>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</p> <p>© Ester van der Voet, 2020</p>	<p>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).</p>
<p>Scenarios</p> <ul style="list-style-type: none"> Modelling supply: specify how demand is supposed to be met <ul style="list-style-type: none"> different production routes different shares of secondary production (circular economy) different efficiency of production processes Separate supply modelling essential <ul style="list-style-type: none"> when supply and demand are not automatically connected when an assessment of waste generation and environmental impacts is required  <p>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</p> <p>© Ester van der Voet, 2020</p>	<p>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.</p>
<p>Scenarios</p> <ul style="list-style-type: none"> Critical materials are a special case Questions to be answered ... seem to be mostly industry related, and mostly short-term BAU: <ul style="list-style-type: none"> will specific industries be able to meet their raw materials requirements in the next few years how can we develop a business case for the production of certain CRMs more general questions, industry and government, are out there as well: <ul style="list-style-type: none"> will there be sufficient raw materials to upscale specific technologies how can we increase supply / develop substitutes / develop alternative technologies / create markets / temporise demand / Choices for modelling limited Essential to distinguish between demand and supply  <p>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</p> <p>© Ester van der Voet, 2020</p>	<p>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</p>







	with their volatile behaviour.
<p>Scenarios</p> <p>Modelling demand of critical materials:</p> <ul style="list-style-type: none"> • top-down modelling impossible <ul style="list-style-type: none"> • no data • production often disconnected from demand • no correlating driving force • so bottom up modelling is the only option <ul style="list-style-type: none"> • modelling of demand for applications • assuming the CRM will be used according to plan <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<p>Scenarios</p> <ul style="list-style-type: none"> • Bottom-up modelling of CRM demand: <ul style="list-style-type: none"> • demand for applications of CRMs • combined with information on CRM content in applications • large data gaps <ul style="list-style-type: none"> • data stops at raw material level: mining, production, and to some extent imports and exports of the raw material • following materials up the supply chain not possible – or not public • Input Output models covering supply chains not suitable <ul style="list-style-type: none"> • translation into monetary terms doesn't make sense • insufficient level of detail in sectors <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<p>Scenarios</p>  <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<p>Scenarios</p> <p>Tantalum flows in EU (Deetman et al., 2018)</p>  <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<p>Scenarios</p> <p>First attempt to harmonise quantification of appliances as well as material content: ProSUM project (http://www.prosumproject.eu/)</p> <p>stock of Li in batteries EU</p>  <p><small>© Ester van der Voet, 2020</small></p>	<p>The EU H2020 ProSUM project has done groundbreaking work in the classification of appliances to a level that is sufficiently 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.</p>

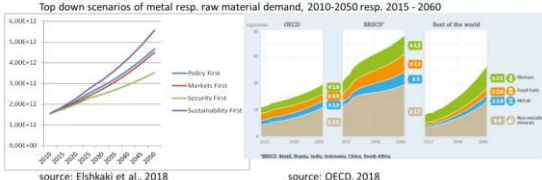
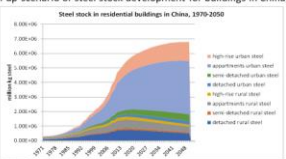
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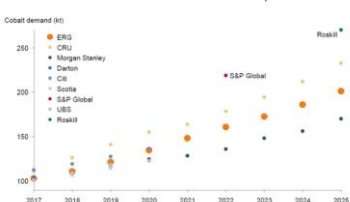
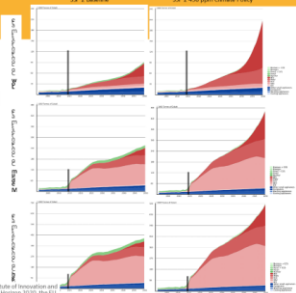
<h2>Scenarios</h2> <p>Modelling supply of CRMs?</p> <ul style="list-style-type: none"> • Dependent on many things besides demand <ul style="list-style-type: none"> • prices • demand for host material • share of secondary production • • Models of little use <ul style="list-style-type: none"> • supply chain resilience models? • In scenario exercises, focus is usually on demand <p><small>© Ester van der Voet, 2020</small></p>	
<h2>Scenarios</h2> <p>Bottom line of scenario exercises so far:</p> <ul style="list-style-type: none"> • CRMs either have to become a regular commodity ... • ... or they will not be used in appliances at a large scale in the long run. <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<h2>Scenarios</h2> <p>References</p> <ul style="list-style-type: none"> • British Geological Survey https://www.bgs.ac.uk/ downloadable data for mineral production worldwide • International Energy Agency (2008). Energy Technology Perspectives. • International Resource Panel (2019). Global Resources Outlook. • Van der Voet, E., L. van Oers, M. Verboon & K. Kuipers (2019). Environmental Implications of Demand Scenarios for Metals, Methodology and Application to Seven Major Metals. <i>Journal of Industrial Ecology</i> 23(1) pp 141-155. • Eshiki, A., T. E. Graedel, L. Ciacci, and B. K. Reck (2018). Resource Demand scenarios for the major metals. <i>Environ Sci Technol.</i> 2018 Mar 6; 52(5): 2491-2497 • OECD, 2018. Global Material Resources Outlook to 2060 – Economic Drivers and Environmental Consequences. • Marinova, S., S.P. Deetman, E. van der Voet & V. Daigoulou (2020). Global construction materials database and stock analysis of residential buildings between 1970-2020. <i>Journal of Cleaner Production</i> 247 (2020) 119-146 • Deetman, S.P., L. van Oers, E. van der Voet & A. Tukker (2018). Deriving European Tantalum Flows using Trade and Production statistics. <i>Journal of Industrial Ecology</i> 22(1), 166-179 • Deetman, S., S. Pauliuk, D. van Vuuren, E. Van Der Voet, A. Tukker (2018). Scenarios for demand growth of metals in electricity generation technologies, cars and electronic appliances. <i>Environmental Science & Technology</i> 52 (8), pp 4950-4959. • Deetman, S., N. Mancheri, A. Tukker, T. Brown, E. Petavratzi, L. Tercero Espinoza (2019). Report on the current use of critical raw materials. SCREEN Deliverable 2.1. http://screen.eu/results/ • Tercero Espinoza, L., A. Lobbi, S. Langkau, A. de Koning, E. van der Voet, S. Michaux (2019). Report on the Future Use of Critical Raw Materials. SCREEN Deliverable 2.3. http://screen.eu/results/ <p><small>© Ester van der Voet, 2020</small></p>	
<h2>Scenarios for critical materials</h2> <p>Thank you !!!</p> <p><small>© Ester van der Voet, 2020</small></p>	

Scenarios for critical raw materials: the case of Cobalt

 <p>SCENARIOS FOR CRITICAL RAW MATERIALS, THE CASE OF COBALT</p> <p>ESTER VAN DER VOET LEIDEN UNIVERSITY, INSTITUTE OF ENVIRONMENTAL SCIENCES</p> <p><small>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</small></p>	<p>The first 13 slides contain material also shown in the Scenarios for raw materials lecture.</p>
<p>Scenarios</p> <p>Various definitions of scenarios (dictionaries)</p> <ul style="list-style-type: none"> • a predicted sequence of events • an imagined sequence of events • an outline or model of an expected or supposed sequence of events <p>• <i>Scenarios are plausible, challenging, and relevant stories about how the future might unfold, which can be told in both words and numbers. Scenarios are not forecasts, projections, predictions, or recommendations. They are about envisioning future pathways and accounting for critical uncertainties. (source: UNEP)</i></p> <p><small>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</small> © van der Voet, 2019</p>	<p>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.</p>
<p>Scenarios</p> <p>Scenarios are not precisely defined</p> <ul style="list-style-type: none"> • different scale levels • different actors • different purposes • different types of (or no) quantification • different starting points <p>Scenarios are NEVER predictions They are (plausible)(relevant)(extreme)(possible) stories that help us think about the future</p> <p><small>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</small> © van der Voet, 2019</p>	<p>To illustrate the breadth of the concept of scenario analysis</p>
<p>Scenarios for raw materials</p> <ul style="list-style-type: none"> • Why scenarios for raw materials? • To explore solutions to the resource challenge: <ul style="list-style-type: none"> • The world becomes more populous and richer: demand for resources grows • Supply struggles to keep up, bottlenecks may arise <ul style="list-style-type: none"> • supply problems • waste • environmental impacts • These bottlenecks form the boundary conditions for our use of resources <p><small>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</small> © van der Voet, 2019</p>	<p>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.</p>

<p>Scenarios for raw materials</p> <ul style="list-style-type: none"> • Resource scenarios do not yet exist • At global level, these are being developed <ul style="list-style-type: none"> • by OECD (first effort published at WCEP Oct 2018) • by UN-International Resource Panel • How will / can / might future resource demand develop? • What will be consequences if we do nothing / if we take action for <ul style="list-style-type: none"> • supply • waste • environmental impacts? • Critical materials not (yet) part of these global level efforts <p><small>  This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant Agreement.  This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant Agreement. © van der Voet, 2019 </small></p>	
<p>Scenarios for raw materials</p> <ul style="list-style-type: none"> • Scenarios for (critical) raw materials: <ul style="list-style-type: none"> • storyline development • quantification / modelling • Storyline development we'll do in the exercise • Modelling: for all raw materials but ESPECIALLY critical raw materials it is important to distinguish between modelling DEMAND and modelling SUPPLY <p><small>  This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant Agreement.  This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant Agreement. © van der Voet, 2019 </small></p>	<p>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.</p>
<p>Scenarios for raw materials</p> <ul style="list-style-type: none"> • Modelling demand: • Two possible approaches: “top-down” and “bottom-up” • Top down demand modelling: <ul style="list-style-type: none"> • 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 <p><small>  This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant Agreement.  This activity has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie Grant Agreement. © van der Voet, 2019 </small></p>	<p>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.</p>

<h3>Scenarios for raw materials</h3>  <p>Top down scenarios of metal resp. raw material demand, 2010-2050 resp. 2015 - 2060</p> <p>source: Eishkaki et al., 2018</p> <p>source: OECD, 2018</p> <p>© van der Voet, 2019</p>	<p>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.</p>
<h3>Scenarios for raw materials</h3> <ul style="list-style-type: none"> Modelling demand Bottom up: <ul style="list-style-type: none"> 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 CRMs 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 <p>© van der Voet, 2019</p>	<p>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).</p>
<h3>Scenarios for raw materials</h3> <ul style="list-style-type: none"> bottom-up scenario of steel stock development for buildings in China, 2010-2050  <p>source: Marinova et al., forthcoming</p> <p>© van der Voet, 2019</p>	<p>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).</p>
<h3>Scenarios for raw materials</h3> <ul style="list-style-type: none"> Modelling supply: specify how demand is supposed to be met <ul style="list-style-type: none"> different mines / countries different shares of secondary production (circular economy) different production routes, different efficiency of production processes Separate supply modelling essential <ul style="list-style-type: none"> when supply and demand are not automatically connected when an assessment of waste generation and environmental impacts is required: this depends on technologies. <p>© van der Voet, 2019</p>	<p>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.</p>
<h3>Scenarios for critical raw materials</h3> <ul style="list-style-type: none"> Critical materials are a special case Questions to be answered seem to be mostly industry related, and mostly short-term BAU: <ul style="list-style-type: none"> will specific industries be able to meet their raw materials requirements in the next few years how can we develop a business case for the production of certain CRMs more general questions, industry and government, are out there as well: <ul style="list-style-type: none"> will there be sufficient raw materials to upscale specific technologies how can we increase supply / develop substitutes / develop alternative technologies / create markets / temporise demand / go circular / <p>© van der Voet, 2019</p>	<p>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.</p>

<p>Scenarios for critical raw materials: demand</p> <ul style="list-style-type: none"> Modelling demand of critical materials: top-down modelling usually impossible <ul style="list-style-type: none"> no data production often disconnected from demand no correlating driving force so bottom up modelling is the only option <ul style="list-style-type: none"> modelling of demand for applications assuming the CRM will be used according to plan <p><small>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</small></p> <p><small>© van der Voet, 2019</small></p>	<p>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.</p>
<p>Scenarios for critical raw materials : demand</p> <ul style="list-style-type: none"> Bottom-up modelling of CRM demand <ul style="list-style-type: none"> demand for applications of CRMs combined with information on CRM content in applications large data gaps and high uncertainties <ul style="list-style-type: none"> data stops at raw material level: mining, production, and to some extent imports and exports of the raw material following materials up the supply chain not possible – or not public Input Output models covering supply chains not suitable <ul style="list-style-type: none"> translation from/into monetary terms doesn't make sense insufficient level of detail in sectors material content data absent, or partial, or rapidly changing over time <p><small>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</small></p> <p><small>© van der Voet, 2019</small></p>	<p>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.</p>
<p>Scenarios for critical raw materials: demand</p> <p>Industry Co demand scenarios: short term trends (source: Roskill, 2018)</p>  <p><small>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</small></p> <p><small>© van der Voet, 2019</small></p>	<p>Here starts the new material, with some specific demand scenarios for cobalt. This one from the industry – only until 2025.</p>
<p>Scenarios for critical raw materials: demand</p> <p>bottom-up scenario of Co demand world, SSP2 scenario, until 2050 with assumptions on Co content and on climate policy</p> <p>Co demand in 2050: 90 – 700 kt/y</p> <p>Source: Deetman et al., 2018</p>  <p><small>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</small></p>	<p>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.</p>
<p>Scenarios for critical raw materials: demand</p> <p>What is the composition of products?</p> <ul style="list-style-type: none"> Some data on “where does the material end up in” But very little data on product composition ProSUM project first attempt to systematically collect such data (http://www.urbanmineplatform.eu/homepage) <ul style="list-style-type: none"> for batteries, vehicles and consumer electronics including changes in composition over time unfortunately, database not published <p><small>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</small></p> <p><small>© van der Voet, 2019</small></p>	<p>ProSUM is really a very relevant project and presents lots of materials that can be used for a bottom-up scenario development for CRM.</p>

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

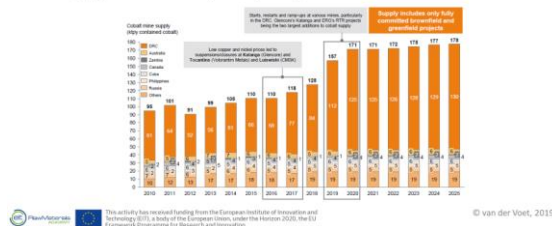
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It is even more difficult to forecast supply as there are many unknowns. For CRMs, supply = demand is way too simplistic.

Scenarios for critical raw materials: supply

- supply scenario for Co (Roskill, 2018)



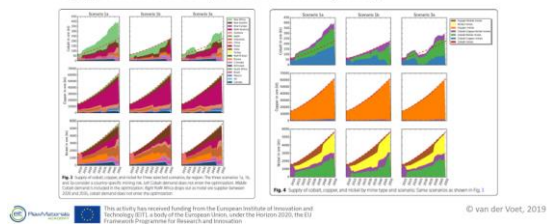
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Supply projections only cover very short periods and depend on present mining operations only.

Scenarios for critical raw materials: supply

- supply scenario for Co (Tisserant & Pauliuk, 2016)



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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)
- Elshakki 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>

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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!

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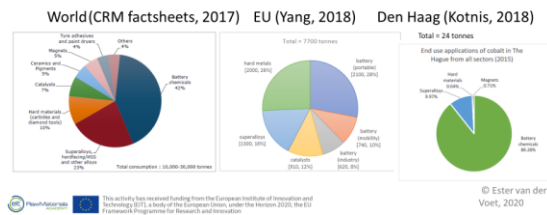
The explanation of the scenario exercise can be found in the hand-out: the Word document called Scenario Storyline Development Exercise.

<p>Scenarios for critical raw materials</p> <p>There are four different types of scenarios (each group selects one via the envelope):</p> <ul style="list-style-type: none"> • rapid energy transition scenario • circular economy scenario • strict sourcing policies scenario • black swan (some disaster happens) <p>Scale is global, time horizon is up to 2050 A business-as-usual is provided, see handout, to use as a reference.</p> <p><small>  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 </small></p> <p><small>© van der Voet, 2019</small></p>	<p>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.</p>
<p>Scenarios for critical raw materials</p> <p>Step 1. specify the “background” system for your scenario</p> <ul style="list-style-type: none"> • socio-economic developments (population, welfare) • technology developments • (geo)political developments • other relevant developments <p>Pay special attention to deviations from trends.</p> <p><small>  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 </small></p> <p><small>© van der Voet, 2019</small></p>	<p>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.</p>
<p>Scenarios for critical raw materials</p> <p>Step 2. Specify demand (bottom-up)</p> <ul style="list-style-type: none"> • 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 <p><small>  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 </small></p> <p><small>© van der Voet, 2019</small></p>	
<p>Scenarios for critical raw materials</p> <p>Step 3. Speculate on consequences. You can use all information you have obtained in this course, or any other, or none, to support you</p> <ul style="list-style-type: none"> • are supply bottlenecks to be expected, and could something be done about that • what are consequences for society at large <p><small>  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 </small></p> <p><small>© van der Voet, 2019</small></p>	
<p>Scenarios for critical raw materials</p> <p>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</p> <p>Step 5: present your scenario in 1 minute</p> <p><small>  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 </small></p> <p><small>© van der Voet, 2019</small></p>	<p>Usually this is a timeline where demand and supply of cobalt are drafted.</p>

Cobalt and Lithium: Potential Supply from the Urban Mine

<p>SusMat Crit</p> <p>COBALT AND LITHIUM: POTENTIAL SUPPLY FROM THE URBAN MINE</p> <p>ESTER VAN DER VOET LEIDEN UNIVERSITY, INSTITUTE OF ENVIRONMENTAL SCIENCES</p> <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	
<p>Co and Li: potential supply from the urban mine</p> <ul style="list-style-type: none"> • The urban mine: has it potential as a (future) source of cobalt and lithium? • very little literature on the topic yet • presentation based mainly on students' research • no attempt to reconcile discrepancies • three scale levels: global, EU and local (Dutch municipality of Den Haag) <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p> <p>In this presentation we focus on Li and Co.</p>
<p>Co and Li resources and reserves</p> <p>EU, CRM factsheets, 2017: geological reserves and resources</p> <p>Estimates of global level resources and reserves</p> <p>Cobalt: 7,100,000 tonnes of Co</p> <p>Lithium: 16,300,000 tonnes of Li</p> <p>European level: bad data, but considerable amounts indicated (though not produced)</p> <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>A tour through the data base for these two raw materials at these three scale levels.</p>
<p>Co primary production (tonnes/year)</p> <p>EU CRM factsheets, 2017: global Co production</p> <div> <p>mined</p> <p>refined</p> </div> <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	
<p>Li primary production (tonnes/year)</p> <p>EU CRM factsheets, 2017: Li production</p> <p>Total of 78,549 tonnes of LiO₂ EU production 200-300 tonnes</p> <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	

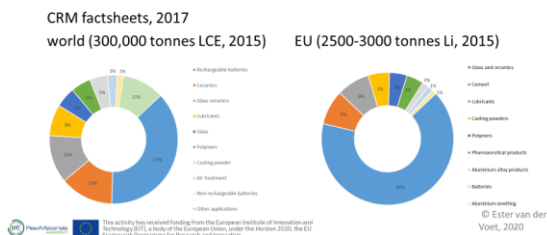
Co end-use (tonnes/year)



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.

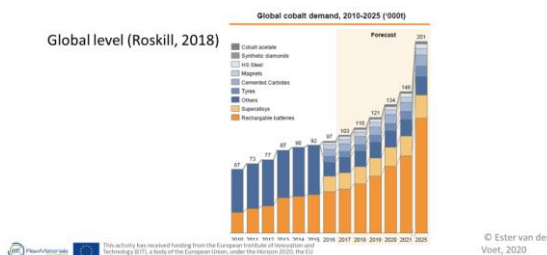
Yang and Kotnis are Master students who did their Master thesis research on cobalt in the EU resp. in the Dutch city of Den Haag (The Hague).

Li end-use (tonnes/year)



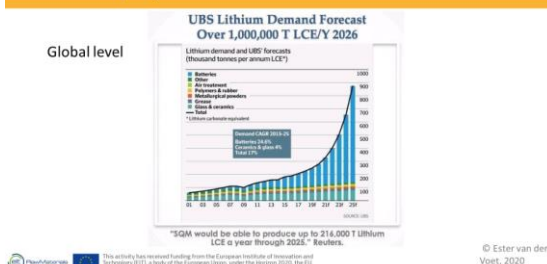
Similar information for lithium. Here, the local level is missing.

Co demand projections

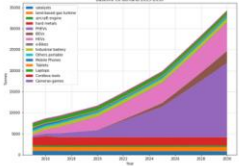
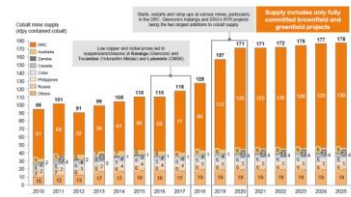
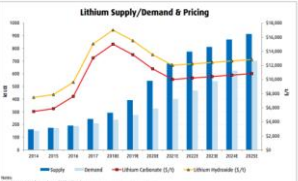


Demand projections for Cobalt only for the VERY near future. Already here we can see an expected rapid rise.

Li demand projections

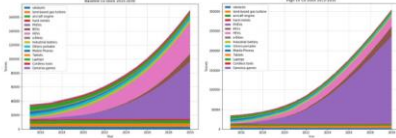


And the same for Lithium.

<h2>Co and Li demand projections</h2> <p>EU level (Yang, 2018) Co projections – Li used in same batteries.</p>  <p>© Ester van der Voet, 2020</p>	<p>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.</p>
<h2>Co supply projections</h2> <p>global level (Roskill, 2018)</p>  <p>© Ester van der Voet, 2020</p>	<p>Supply projections even for the shorter term, based on present mining endeavours and present knowledge only.</p> <p>Comparing supply and demand projections indicate there may be a problem for Cobalt already in the near future.</p>
<h2>Li supply projections</h2> <p>global level</p>  <p>© Ester van der Voet, 2020</p>	<p>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.</p>
<h2>The urban mine of cobalt</h2> <ul style="list-style-type: none"> • For cobalt: already in the near future potential supply issues • What about the urban mine? • First step: how large is the urban mine actually? • Second step: how much comes out of it annually? • Third step: how much of that can be used for secondary Co production? • (... and what would the EoL RIR be if it was?) <p>© Ester van der Voet, 2020</p>	<p>Can the urban mine be a solution? That exploration needs various steps.</p>
<h2>Estimations of the size of the urban mine</h2> <p>How large is the urban mine?</p> <p>Urban mine: stocks of materials that presently are in use (and will become available in due time as waste)</p> <ul style="list-style-type: none"> • Global level (UN-IRP): only one estimate of in-use stocks for Japan, 0.8 kg Co/cap • if multiplied with global population this would be 5000-6000 ktonnes Co • but will likely be much lower, as the Japan number is probably not representative for the world. <p>© Ester van der Voet, 2020</p>	<p>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.</p>

Estimations of the size of the urban mine

How large is the urban mine? Yang, 2018: EU Co in-use stocks rising rapidly from 35 ktonnes at present to 150 or even 300 ktonnes in 2030, especially in car batteries



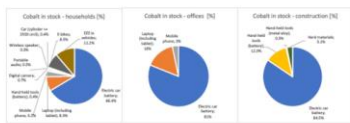
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This is assuming there will not be any supply restrictions, and also assuming the cobalt content of the applications will not change. Those are most likely both untrue assumptions, but making more sophisticated assumptions is very difficult.

Estimations of the size of the urban mine

How large is the urban mine? Kotnis, 2018: in-use stocks of Co in Den Haag



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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.

Estimations of the size of the urban mine

- Urban mine global: < 5000 ktonnes Co (<0.8 kg/cap)
- Geological mine global: >7000 ktonnes (reserves)
- Urban mine EU: 35 ktonnes Co (0.07 kg/cap), rapidly rising
- Geological mine EU: reserves 10-100 ktonnes (bad data)
- Urban mine Den Haag: 67 tonnes Co (0.1 kg/cap)
- No geological mine in Den Haag
- we may at least conclude that the urban mine for cobalt is significant!

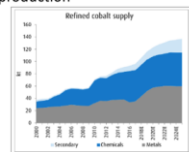
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These rough numbers show at least that the urban mine may be in the same order of magnitude as the geological mine. From this investigation it may also be suspected that the per capita cobalt use is rather in the 0.1 kg/cap order than in the 0.8 kg/cap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

Outflow out of the urban mine

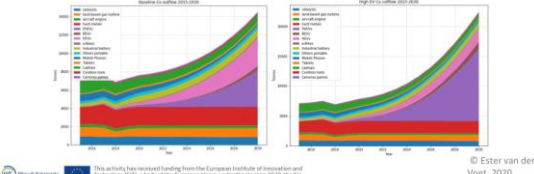


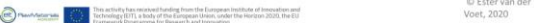
- How much comes out of the urban mine?
- global level: 2.2 ktonnes Co / year secondary production (<https://datamarket.com/data/set/zy0/cobalt-statistics#lds=zy0l8o7=6&display=line>)
- Previous speaker: 38 ktonnes Co/y in 2030
- (compare to demand: 100 – 400 ktonnes Co/y)



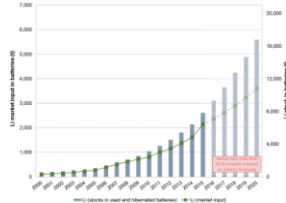


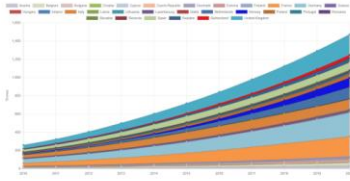
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© Ester van der Voet, 2018

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.

<p>Outflow out of the urban mine</p> <ul style="list-style-type: none"> • 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)  <p>© Ester van der Voet, 2020</p>	<p>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.</p>
<p>Outflow out of the urban mine</p> <ul style="list-style-type: none"> • Kotnis, 2018: presently 8 tonnes Co/year flows out of the urban mine of Den Haag  <p>© Ester van der Voet, 2020</p>	<p>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.</p>
<p>How much urban mine material is used?</p> <ul style="list-style-type: none"> • Present recycling rates, global level: <ul style="list-style-type: none"> • 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  <p>© Ester van der Voet, 2020</p>	<p>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.</p>
<p>How much urban mine material is used?</p> <ul style="list-style-type: none"> • EU: EoL RIR = 0% (CRM factsheets 2017) • EU: EoL RIR = 35% (EC Report CRMs and the Circular Economy) • Den Haag: unknown!  <p>© Ester van der Voet, 2020</p>	<p>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.</p>

<p>How much urban mine material could be used?</p> <ul style="list-style-type: none"> • Probably much more could be used than actually is used • Recyclable applications large part of total <ul style="list-style-type: none"> • demand expected to increase rapidly • recyclable is not the same as actually recycled <p><small>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.</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>Technically it is probably possible to increase EoL recycling rates, as the recyclable applications form a large part of the total.</p>
<p>Urban mining for Lithium</p> <p>Situation for Lithium is different:</p> <ul style="list-style-type: none"> • no (primary) supply problems expected anytime soon • potential very large source in future: sea water • urban mining not urgent from supply point of view • present recycling rates close to 0 <p>Discussion:</p> <ul style="list-style-type: none"> • other reasons to go for urban mining? <p><small>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.</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<p>Urban mining for Lithium</p>  <p><small>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.</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<p>Urban mining for Lithium</p>  <p><small>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.</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<p>Li stock-in-use in EU (tonnes)</p> <p>CRM factsheets, 2017 (from ProSUM project)</p>  <p><small>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.</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>In the ProSUM project, some (short-term) estimates are made of the urban mine for EU and member states.</p>

<p>Li outflow from stock in Europe (tonnes/year)</p> <p>CRM factsheets, 2017 (from ProSUM project)</p>  <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>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.</p>
<p>Conclusions</p> <ul style="list-style-type: none"> • The urban mine for cobalt at all scale levels is significant: same order of magnitude as geological reserves • The urban mine is growing rapidly and will probably continue to do so over the next decades • The urban mine will become more relevant as a source of materials • The information on the urban mine is poor and urgently needs to be expanded and taken up in “official” investigations and statistics • Geological surveys and national statistics bureaus seem indicated as institutions to take this up. <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	<p>Preliminary conclusions: for supply security as well as environmental reasons it is worthwhile to start exploring the possibilities for urban mining.</p> <p>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.</p>
<p>References</p> <p>EC, DG Growth, 2017. Study on the Review of the List of Critical Materials. Critical Raw Material factsheets. Luxembourg, ISBN 978-92-79-72119-9</p> <p>Yang, Y. 2018: Estimating European demand and recycling potential of cobalt until 2030. MScIE thesis report, Leiden/Delft Universities.</p> <p>Kotnis, J. 2018: Critical Raw Materials in the City: recycling perspectives for cobalt in The Hague. MScIE thesis report, Leiden/Delft Universities.</p> <p>Roskill, 2018: Presentation Battery Supply Chain Europe 2018</p> <p>Hamilton, C. 2017: Cobalt: Solving for a Supply Constrained market. BMO capital markets, Global Commodities, 4 december 2017</p> <p>European Commission Staff Document Report on CRMs and the circular economy. Brussels, 16-1-2018, SWD(2019)36 final</p> <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	
<p>Conclusions</p> <p>Thank you!</p> <p><small>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</small></p> <p><small>© Ester van der Voet, 2020</small></p>	

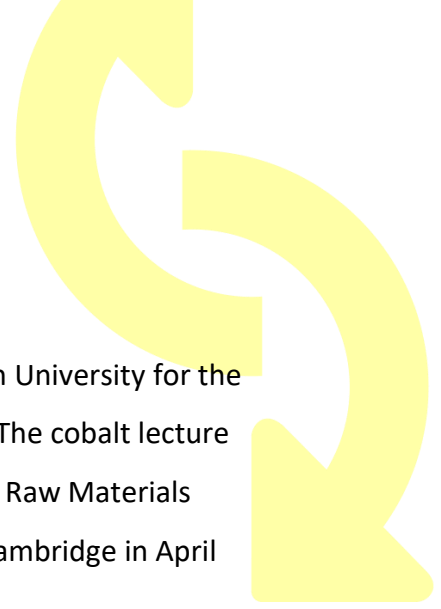
3 Exercises

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

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