Teaching Resources on the Sustainable Management of Critical Raw Materials

Trainer's Manual for Supply Chain Resilience

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.

The collection of training manuals presents the key messages related with the sustainable management of critical raw materials in three major sections:

- Introduction to criticality
- Analysis of criticality
- Solutions for sustainable management

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

The overall goal of the SusCritMat project is to qualify lecturers to teach the topics themselves. Therefore, the teaching resources do not only provide an introduction and improved insight into selected thematic issues, but also deliver a set of teaching materials "ready-to-use".

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

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1.1 Training Materials List

The *SusCritMat project* developed the following teaching materials:

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

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1.2 Suggested timetable

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

- Lecture: 45 minutes
- Exercise: discussion forum guided by the instructor. A one-pager report can be asked to students as a reflection.

1.3 Key Messages

This training module introduces the basics of supply chain resilience. The module includes:

- A presentation on the basics of Supply Chain Resilience and the complexity behind critical materials
- A discussion forum exercise on resilience of critical materials

The lecture introduces the students to the concept of criticality in relationship with supply chain disruptions. With examples from disruptions in a number of supply chains (e.g. including the 2010 REE crisis), the concept of resilience is introduced. Various types of disruptions are introduced that relate to supply and demand of critical materials.

1.4 Learning Objectives

- Understanding of the basics of resilience
- Understanding when a supply chain can be disrupted
- Comprehending the basic types of disruptions and the context in which they take place
- Analysing historical trends of disruption for minor metals, and the role of stakeholders in determining such disruptions.

1.5 Additional Reading

- Sprecher, B., Daigo, I., Spekkink, W., Vos, M., Kleijn, R., Murakami, S., & Kramer, G. J. (2017). Novel indicators for the quantification of resilience in critical material supply chains, with a 2010 rare earth crisis case study. Environmental science & technology, 51(7), 3860-3870.

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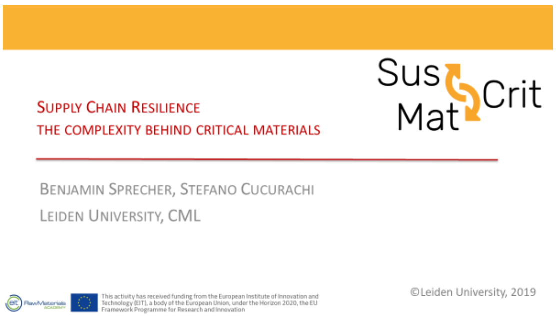
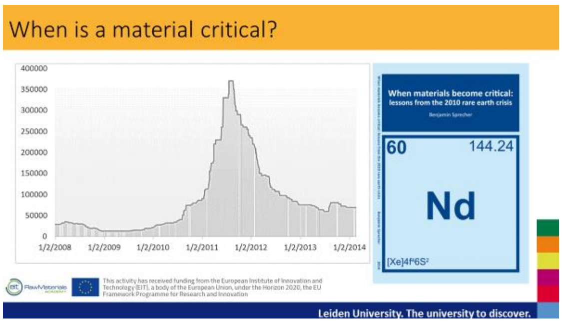
- Sprecher, B., Daigo, I., Murakami, S., Kleijn, R., Vos, M., & Kramer, G. J. (2015). Framework for resilience in material supply chains, with a case study from the 2010 rare earth crisis. Environmental science & technology, 49(11), 6740-6750.
- Nuss, P., Graedel, T. E., Alonso, E., & Carroll, A. (2016). Mapping supply chain risk by network analysis of product platforms. Sustainable Materials and Technologies, 10, 14-22.

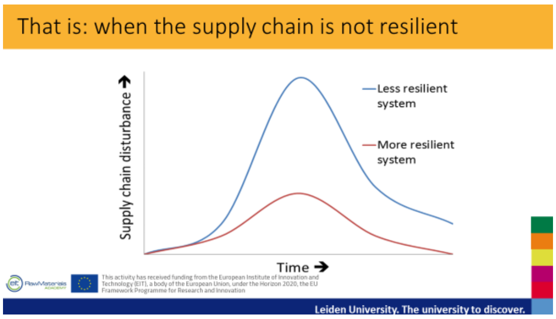
2 Slides and Notes

Slides are supplied in ppt format with annotations.

	
	First we need to define critical materials. Historical data can be a good starting point as it allows grasping the dynamic relationship between stocks and supply vs. demand for a certain material. Neodymium (Nd) is a very good case study for critical materials. It is widely used. For example, there is roughly 1 gram of Nd in earphones, 1 kg in electric cars and more than a ton in a direct drive wind turbine. There are several aspects that determine the criticality of Nd. The graph in the slide pictures the price of neodymium in Yuan. All of a sudden, due to geopolitical conflicts, in 2011 China blocked exports of Nd to Japan, and then immediately to the rest of the

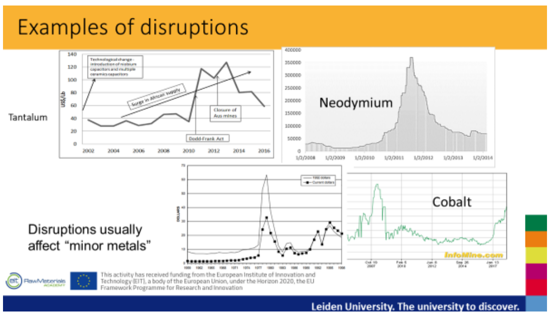
world. The geopolitical context of Nd in this case affected its price on the stock market, thus its perceived criticality. However, pretty soon the price came crashing down again, thus showing that the Nd supply chain also has some resilience.

On the right side of the screen you can see the cover of the doctoral thesis of dr. Benjamin Sprecher from CML on one critical material: Neodymium (Nd).



The resilience of a system can be evaluated based on its ability to respond to a disturbance, and on the ability of the system to return to a stable status after a disturbance. Take the supply chain of Nd: the system poorly responded to the disturbance determined by China’s new policy back in 2011. The system reaction proved that the Nd supply was not very resilient, but did have a certain amount of resilience.

Sprecher, B., Daigo, I., Murakami, S., Kleijn, R., Vos, M., & Kramer, G. J. (2015). Framework for resilience in material supply chains, with a case study from the 2010 rare earth crisis. *Environmental science & technology*, *49*(11), 6740-6750.



Similar disruptions can be seen for other metals, especially for minor metals.

Price graphs based on infomines.com information. Tantalum graph reference: Mancheri, N. A., Sprecher, B., Deetman, S., Young, S. B., Bleischwitz, R., Dong, L., ... & Tukker, A. (2018). Resilience in the tantalum

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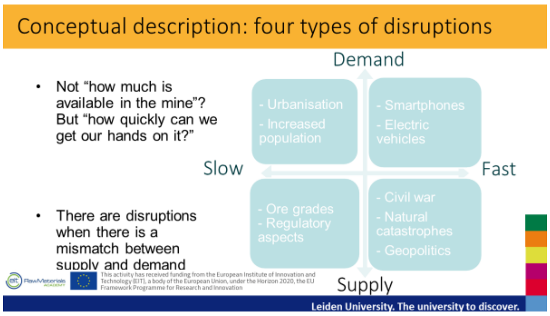
	supply chain. *Resources, Conservation and Recycling*, *129*, 56-69.
	It is important to note that critical materials are often minor metals. As a result, the question is usually not how much there is (there is usually still a lot in the earth crust), but on how much is available at a specific scale of production. And because of the limited production and availability, you may have a situation in which the increase in demand for one application (e.g. Smartphones), a natural catastrophe (e.g. flood), or a policy decision could destabilize the global market. Disruptions are the core. Supply disruptions are interruptions in the supply of a product due to external factors. Such factors can be determined by policy decisions, but also by the interruption of a service along the supply chain. Be it limited inventory, inaccurate demand forecasting or natural disasters, supply chains are easily destabilized by a myriad of factors. The result is a significant impact on the availability of a material. In the matrix reported here, you see how supply and demand relate to each other when a disruption hits a system. Sprecher, B., Daigo, I., Spekkink, W., Vos, M., Kleijn, R., Murakami, S., & Kramer, G. J. (2017). Novel indicators for the quantification of resilience in critical material supply chains, with a 2010 rare earth crisis case study. *Environmental science & technology*, *51*(7), 3860-3870.

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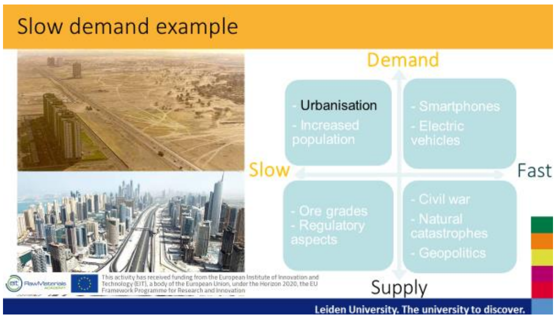
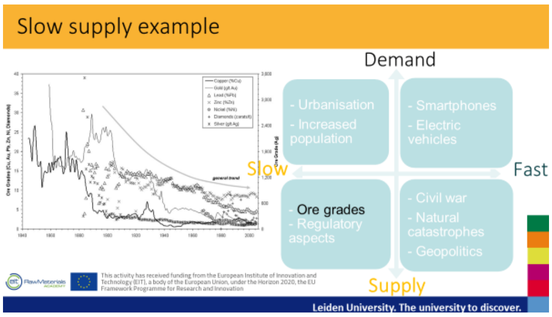
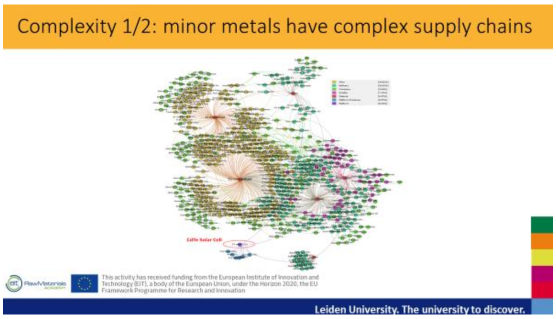
	Here you see an example of a slow demand system. The rapid urbanization of a city (Dubai in photo) determines a gradual increase in the demand for resources.
	The slow trends of ever-increasing demand for materials and at the same time decreasing ore degrees is why we really need a circular economy. Graph from: Mudd, G. M. (2007). The sustainability of mining in Australia: key production trends and their environmental implications. *Department of Civil Engineering, Monash University and Mineral Policy Institute, Melbourne*.
	The level of complexity of the supply/demand systems for critical materials is a major challenge to the resilience of such systems. Factors such as the ownership structure, technical capacity, proven stocks all contribute to influence how the system behaves. The past cannot always be used to prospect the future performance of such systems. Factors as price are also volatile, and actual prices are often not publicly known. Typical transactions involving critical materials are relatively small in volume. As a consequence, and error in the wrong place in the supply chain can disrupt the entire system.

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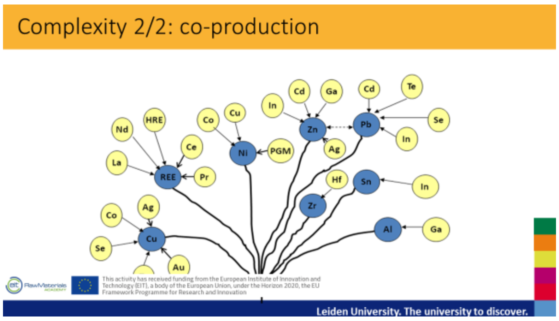
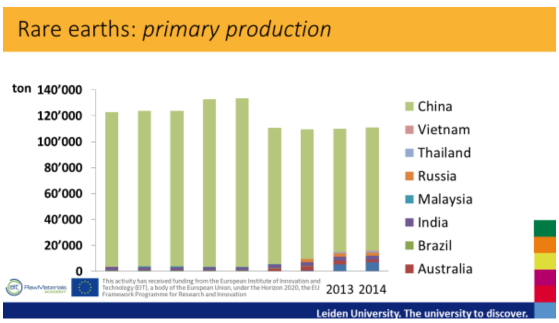


So-called companionship adds another layer of complexity to the resilience of the supply-demand system for critical materials. Take the case of indium and zinc: there are 66 grams of indium per ton of zinc. And nobody is going to produce a million tons of extra zinc just because you need a little more indium. And vice versa, if the demand for zinc falls, your indium production will also irrevocably fall.

For example, there was a shortage of cobalt in 2018, because maintenance was being carried out on a large copper mine. For the huge copper market, that one mine doesn't really matter, but for cobalt it was a huge disruption.

Figure from presentation 'The Future of Metals', by Thomas E. Graedel, Center for Industrial Ecology, Yale University



Consider now the primary production of rare earths. From a mining operation, the output can be an ore or oxide or sulphate.

In this graph we show the production side of things. The 2010 REE crisis can also be seen here, and it is also striking that production remained at a lower level for a very long time, despite the fact that the crisis had already ended.

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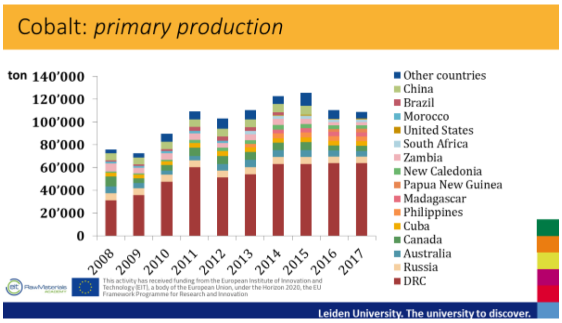
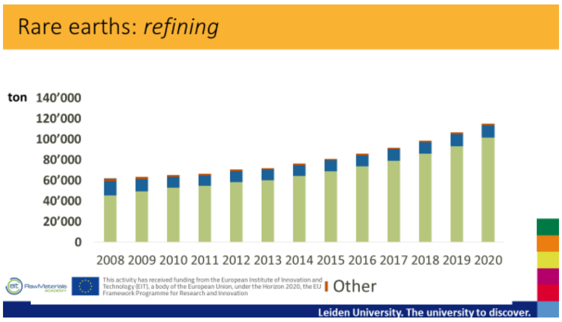
	That is the effect of substitution, on which we will return to shortly. Sprecher, B., Daigo, I., Spekkink, W., Vos, M., Kleijn, R., Murakami, S., & Kramer, G. J. (2017). Novel indicators for the quantification of resilience in critical material supply chains, with a 2010 rare earth crisis case study. *Environmental science & technology*, *51*(7), 3860-3870.
	An additional level of complexity comes from the social dimension of the primary production. Red was not chosen by accident in this graph, as many of the minor metals are being won under terrible circumstances, and terrible images have popped up in the media related to the living conditions of those operating in the mining business. An example is the Cobalt in the Congo. Data based on USGS (2017).
	The step of refining of the mined matter in the supply chain shows a different picture. Note here that refining an oxide to the alloy is much more difficult and adds much more value. Sprecher, B., Daigo, I., Spekkink, W., Vos, M., Kleijn, R., Murakami, S., & Kramer, G. J. (2017). Novel indicators for the quantification of resilience in critical material supply chains, with a 2010 rare earth crisis case study. *Environmental science & technology*, *51*(7), 3860-3870.

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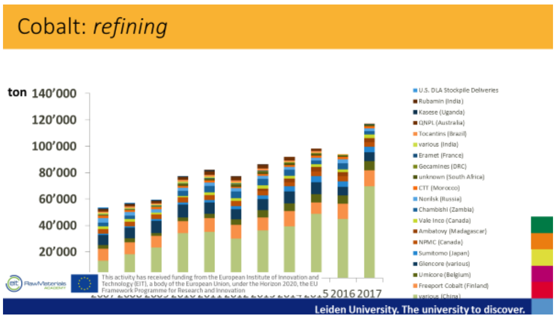
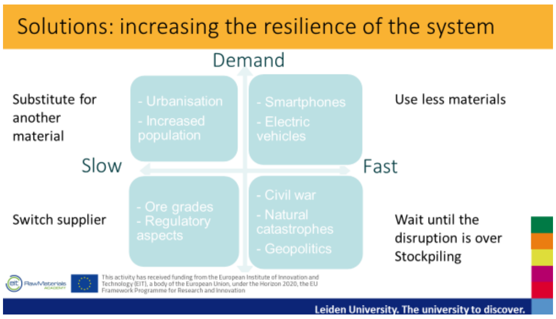
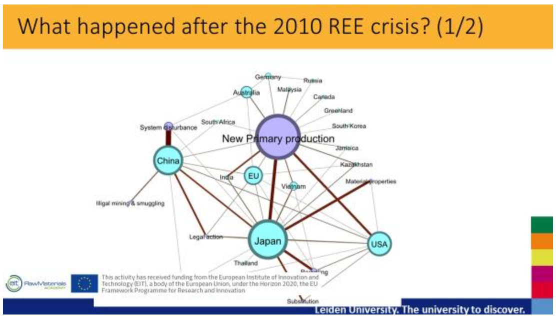


Who has the patents, who has made the investments, to have exactly that one link in the chemical chain with which you make the difference? Then it no longer matters where it is extracted, China remains the only one who can do something with it.

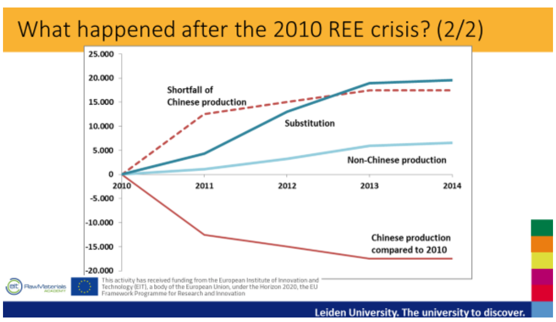


Let us take a look at some solutions. For each disruption type previously discussed, there is a type of solution.



This is the result of an event sequence analysis, where we tracked a number of events and tagged them. What you see is that most news items were related to a few countries (japan, china, USA), and almost all were about making new mines.

Sprecher, B., Daigo, I., Spekkink, W., Vos, M., Kleijn, R., Murakami, S., & Kramer, G. J. (2017). Novel indicators for the quantification of resilience in critical material supply chains, with a 2010 rare earth crisis case study. *Environmental science & technology*, *51*(7), 3860-3870.



Using another method we estimated how much REE supply loss was compensated for and how. We found that actually most impact came from substitution, not new mining.

Sprecher, B., Daigo, I., Spekkink, W., Vos, M., Kleijn, R., Murakami, S., & Kramer, G. J. (2017). Novel indicators for the quantification of

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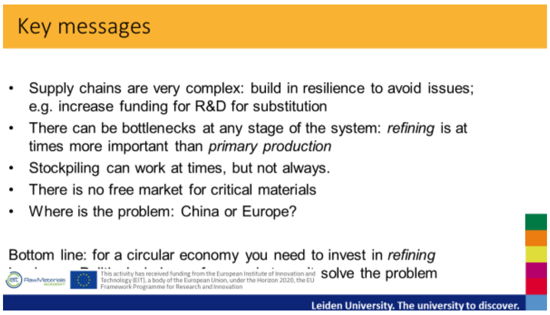
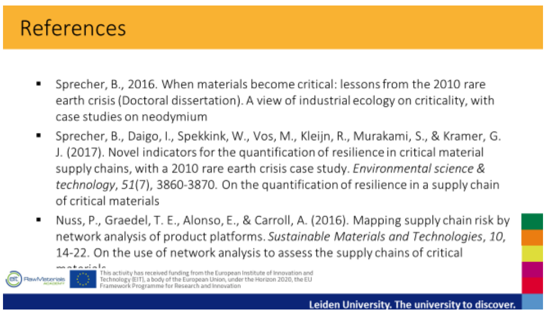
<table>
<tr><td></td><td>resilience in critical material supply chains, with a 2010 rare earth crisis case study. Environmental science & technology, 51(7), 3860-3870.</td></tr>
<tr><td>
</td><td>Is stockpiling a seemingly simple solution? Stockpiling refers to the activity of accumulating a resource to face moments of instability and market volatility.

Here you see pictures of the USA strategic stockpile.</td></tr>
<tr><td>
</td><td>And that stockpile has really cost billions, $ 150 million a year investment up to the 90s. That huge mountain of asbestos shows how difficult it is to make the right decision, in such a complex system as we saw earlier, where would you start building a stock?

Perkins, P. E. (1997). World Metal Markets: The United States Strategic Stockpile and Global Market Influence. Greenwood Publishing Group.</td></tr>
<tr><td>
</td><td>The level of complexity behind critical materials requires preventive actions. Here you see some key elements of attention to assess the resilience of systems of supply of critical materials.</td></tr>
<tr><td>
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eit RawMaterials ACADEMY

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3 Discussion forum input

The intention of the exercise is to stimulate online discussion on a forum platform about supply chain resilience. After the content lecture in class the instructor posts on the education online platform of preference the following:

- Look at the price history of a minor metal of choice
- Identify price peaks
- Look back in the news discussions of the time in which the price peak took place and identify the following:
    - Are there elements that point in the direction of the cause or causes of potential disruption?
    - Can you speculate on how various actors in the supply chain could have prevented the price peak and the consequent impacts on the supply chain?
    - Which of the following actors was involved?
        - Mining companies
        - Refining companies
        - OEMs
        - Consumers
        - Governments

The students are asked to submit individual posts in the forum (of length of about a page including relevant links). Peer discussion is advised. The lecturer will identify in class elements of interest and discuss them with the students.

4 Acknowledgements and Authors

This teaching material was prepared by Benjamin Sprecher and Stefano Cucurachi, Leiden University.

The following authors have contributed to prepare the complete teaching material kit and intend to provide an overview of major topics surrounding the sustainable management of critical raw materials:

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Ruud Balkenende, TU Delft

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Patrick Wäger, Empa

Jan-Henk Welink, TU Delft

Steven Young, University of Waterloo

Besides, many others invested their time and expertise to discuss and review this teaching material.

5 Citation

Please cite the SusCritMat teaching material as follows when using them for your curriculum:

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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/.

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