Teaching Resources on the
Sustainable Management of Critical Raw Materials

Trainer's Manual for

Environmental Aspects

January 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

Table of Contents

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

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.

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

1.1 Training Materials List

The *SusCritMat project* developed the following teaching materials:

1	Critical Resources for emerging technologies
2	Circular Economy
3	Criticality
4	LCA
5	Responsible Mining
6	Responsible Sourcing/Certification
7	Closing Loops on Product Level
8	MFA
9	Geopolitical aspects
10	Metals & CRM scenarios
11	Sustainability Assessment
12	Waste Management
13	Simulation-based Design for Recycling
14	Restricted Substances Legislation
15	Historical solutions for CRM
16	Characterizing the Urban Mine
17	**Environmental Aspects**
18	Process Models based on LCA
19	Responsible Business Practices
20	Supply chain resilience
21	Sustainable materials usage
22	CRM and Sustainable Development
23	Circular Business Models
24	Economy of rare metals
25	Supply Risk factors
26	Recycling
27	Good Use of Data

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.

Estimated time for the lecture: 55 minutes
Estimated time for the quiz & discussion of the answers: 10 minutes

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

1.3 Key Messages

Our lifestyle and economic growth are currently involved with high environmental impacts and a large need for primary resources. According to ISO 14001 related to '*environmental system management*', an environmental impact can be described as a change in the environment, negative or positive, resulting partly or totally from human activities, products or services (*i.e.* an anthropogenic cause). In this lecture, two distinct categories of environmental impacts are considered: on the one hand, environmental impacts due to chemical/physical emissions from the technosphere to the ecosphere (see Figure 1); on the other hand, environmental impacts that come from resource extraction, deprivation or depletion for anthropogenic purposes.

Hence, the present lecture aims to present the main environmental impacts considered in environmental evaluations of products, activities or services. For each one, the environmental problem is first described. Then, the underlying environmental mechanisms and fundamental modelling principles are explained. Finally, the main anthropogenic sources causing the problem are highlighted.

This lecture covers nine of the most common environmental impacts: Climate change / Ozone depletion / Photochemical ozone (smog) / Aquatic eutrophication / Acidification / Human toxicity / Eco-toxicity / Resource depletion and Land use. This is a first didactic step allowing to further undertake the measure of these impacts using quantitative assessment methodologies (e.g. Life Cycle Assessment) and then minimise them *via* eco-design practices.

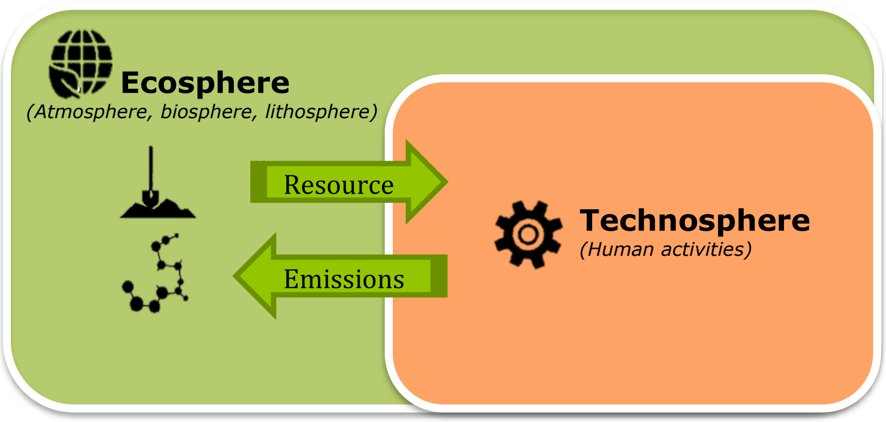


Figure 1 - Potential environmental impacts are due to substance emissions or resource depletion/deprivation

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

1.4 Learning Objectives

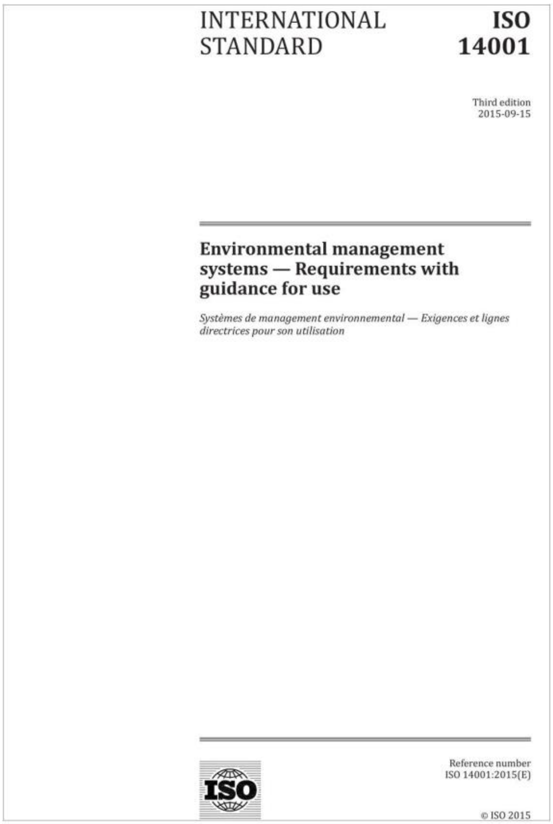
After attending this lecture, the learner should be able to **differentiate** and **describe** each of the main environmental aspects considered in life cycle impact assessment methodologies. Thus, the learning objectives are the following:

- To identify the environmental aspects caused by a given human activity
- To link these aspects to potential environmental impacts used in life cycle impact assessment methodologies
- To understand the environmental mechanisms leading to a particular impact and its fundamental modelling principles
- To determine the main anthropogenic sources causing the targeted environmental impact

1.5 Additional Reading

- **ISO 14001:2015** Environmental management systems - Requirements with guidance for use

ISO 14001:2015 specifies the requirements for an environmental management system that an organization can use to enhance its environmental performance.


INTERNATIONAL STANDARD

ISO 14001

Third edition
2015-09-15

Environmental management systems — Requirements with guidance for use

Systèmes de management environnemental — Exigences et lignes directrices pour son utilisation

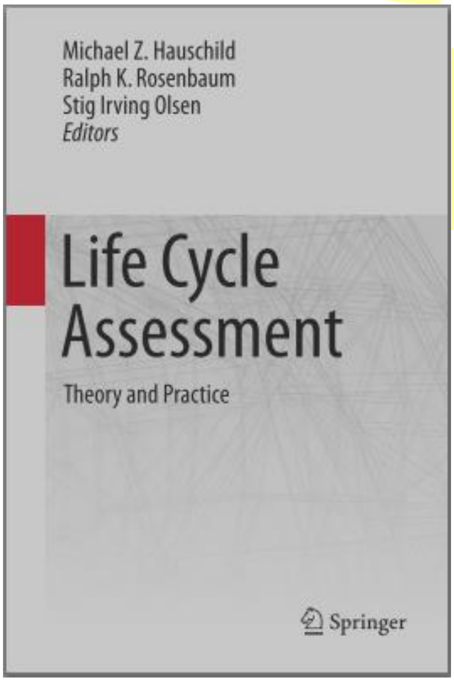
Reference number
ISO 14001:2015(E)

© ISO 2015

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

- **LCA Theory & Practice : Chapter 10 – Life Cycle Impact assessment**. Rosenbaum, R. K. *et al.* (2018). pp. 633–959. https://doi.org/10.1007/978-3-319-56475-3

Up-to-date and complete LCA textbook that explains, among others, environmental impact mechanisms



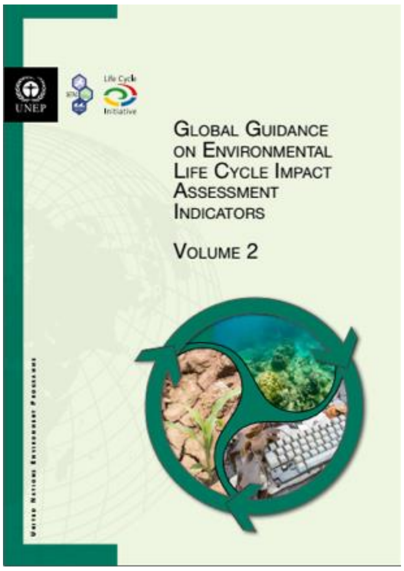
- **International Reference Life Cycle Data System (ILCD) Handbook : Recommendations for Life Cycle Impact Assessment in the European context.** European commission-JRC. (2011).. EUR 24571 EN. *European Commission*, 159. https://doi.org/10.2788/33030

Recommendations of impact assessment methods from the European Commission.

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

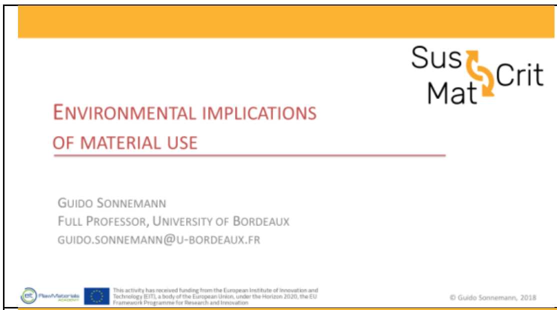
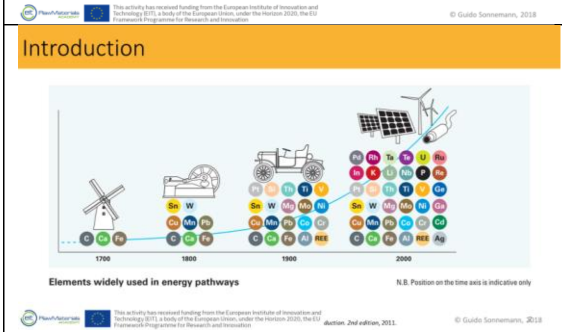
* R. Frischknecht and O. Jolliet, *Global Guidance on Environmental Life Cycle Impact Assessment Indicators Volume 2*, 2019.

Recent recommendations of the UNEP/SETAC Life Cycle Initiative on method selection and future method development.

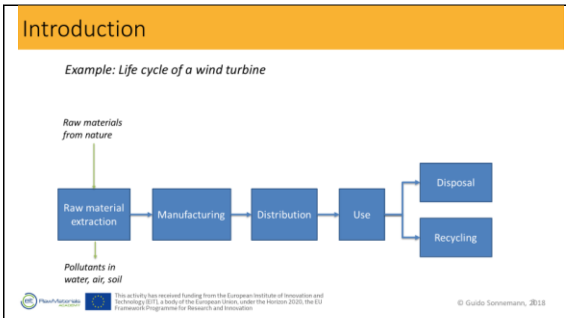


2 Slides and Notes

Include PP slides and notes here.

<table>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>
</td>
<td>Technologies become more sophisticated, more performant, and more energy efficient. This technology development requires a much larger selection of raw materials than in the past. Materials become also increasingly complex, by mixing raw materials in innovative alloys.
On the other hand, these complex mixes are very difficult to recycle due to incompatible combinations of raw materials for separation techniques, or because materials are used in very small fractions. These materials are lost, or dissipated, in other materials that are easier to recycle, such as aluminum, copper, and steel.</td>
</tr>
</table>

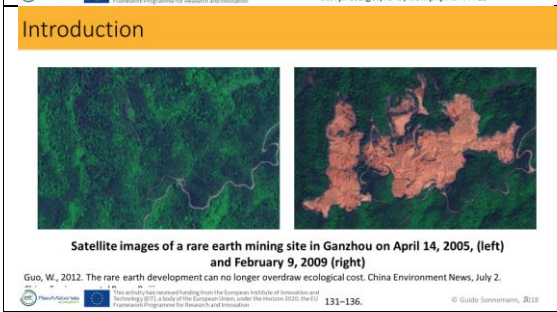
This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation



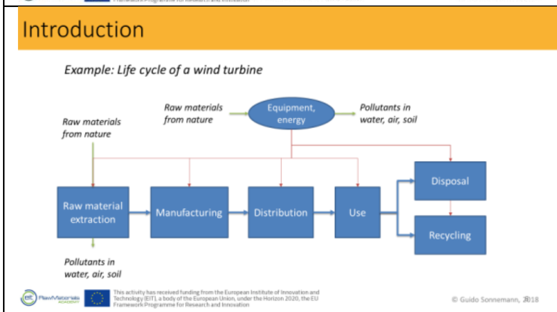
Take for example the life cycle of a wind turbine. The life cycle starts with raw material extraction. Raw materials are manufactured into components that make the wind turbine. The wind turbine is transported to its final location, where it is taken into use. During use, it will require maintenance to guarantee lifetime operation. Finally, some parts will be recycled, and some parts will be disposed of.

Each step in this life cycle will cause interactions with the environment: environmental exchanges. The most obvious step is the "raw material extraction" phase. Metals are taken from the earth's crust, water is used, and waste streams contain toxic elements, particulate emissions, or simply CO2 that ends up in the atmosphere, and in rivers, lakes, and the soil.

Examples of raw materials that are used in wind turbines are rare earth elements. The Bayan Obo mine is a large deposit for neodymium, which is produced as a by-product of iron. The satellite image shows the impact of the mining activity on the environment due to large production of wastes and land use.

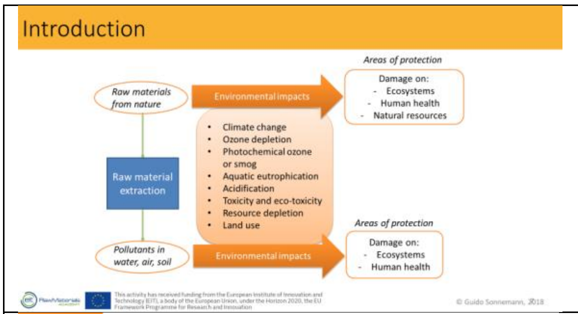


This is another rare earth deposit. In this ion-adsorption deposit, more heavy rare earth elements are mined, such as dysprosium. The satellite image shows a high impact on deforestation, with consequences on, among others, soil erosion and biodiversity.

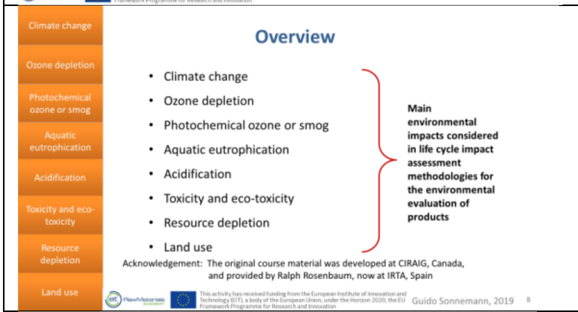


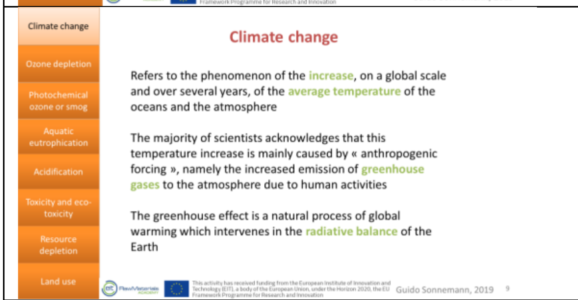
In fact, in each life cycle stage, equipment and energy are used that cause environmental interactions as well. Energy burnt during raw material extraction will lead to CO2 emissions, use of cleaning products during the maintenance of the wind turbine leads to polluted water and soil, equipment used during manufacturing also require raw material extraction and manufacturing and disposal of the equipment. Furthermore, each life cycle stage can cause direct exchanges with the environment due to inefficiencies and material losses.

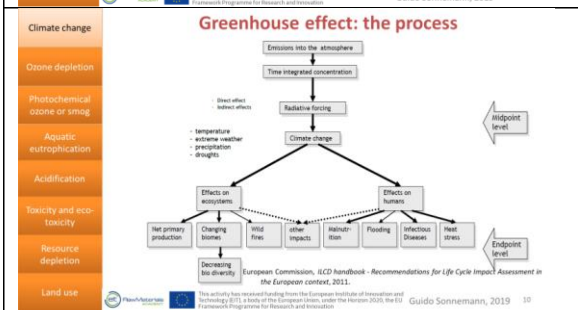
This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation



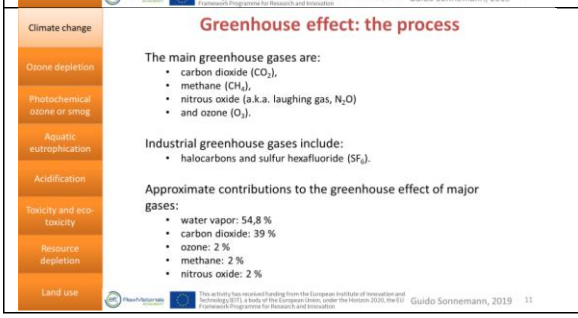
In a Life Cycle Assessment we evaluate to what extent the extraction on resources and the emission of substances have an impact on the environment, where we consider different impact categories. These impact categories contribute to damages in three areas of protection: ecosystems, human health, and/or natural resources.





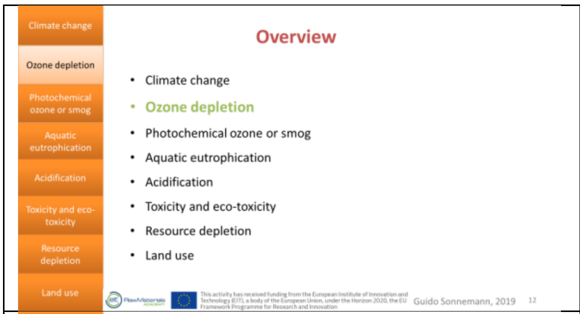


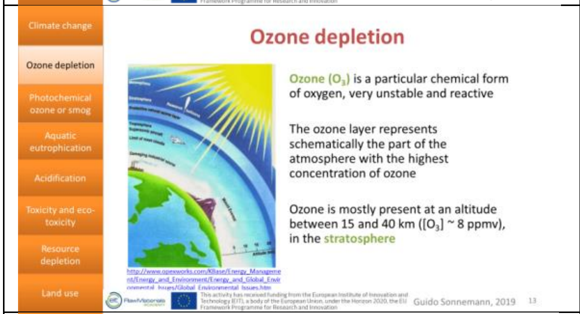
This figure shows the impact pathway of the greenhouse gas effect. CO2 emissions contribute to radiative forcing, which results in climate change. Climate change has further an effect on ecosystems and on human health, which are the areas of protection evaluated in LCA.

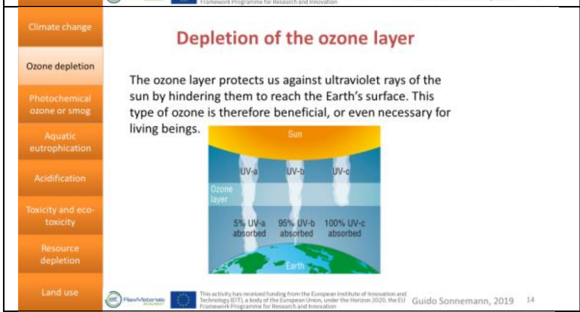


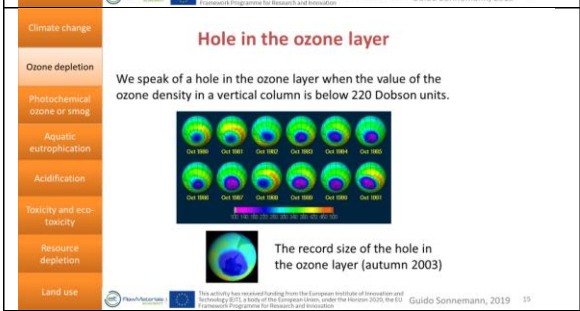
This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

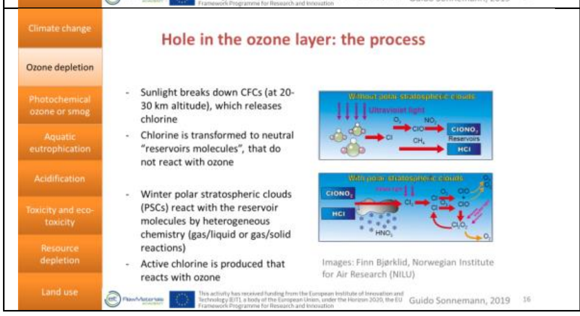
Sus Mat Crit



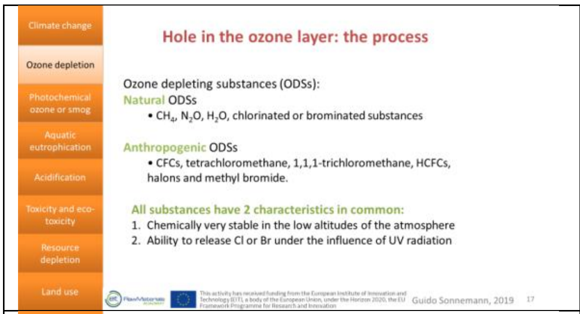


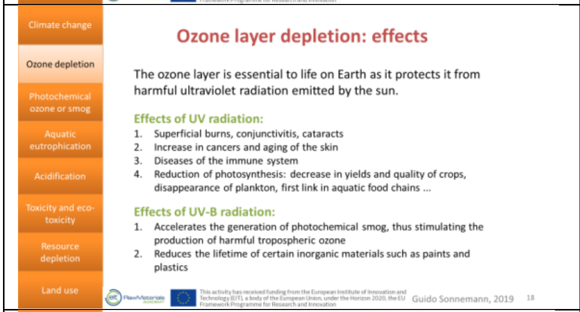


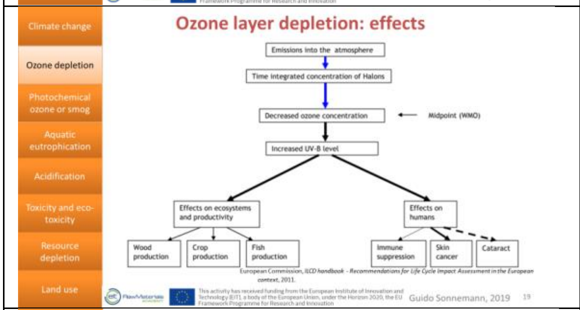




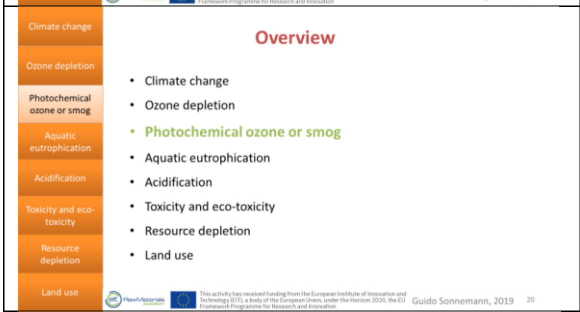
This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

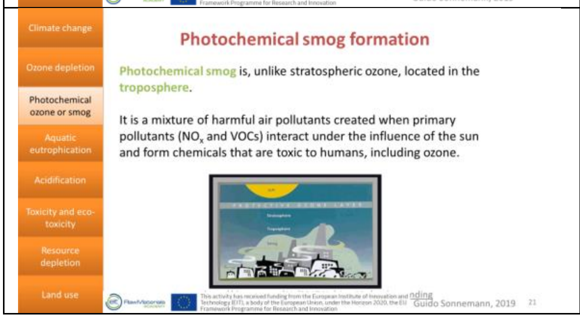




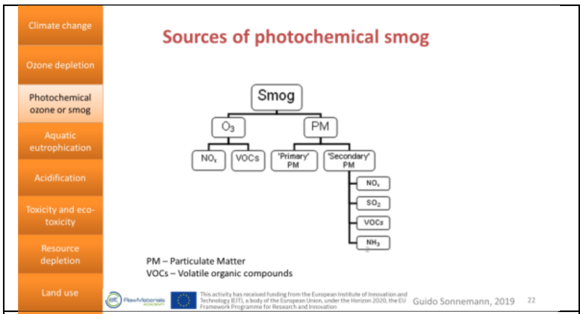
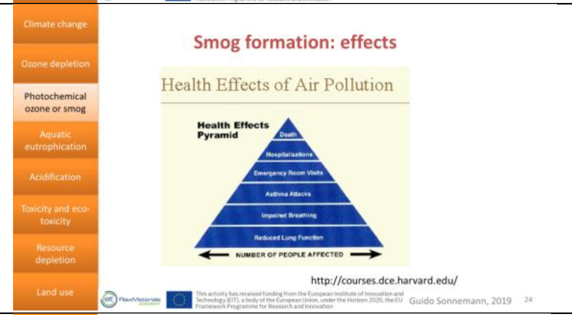
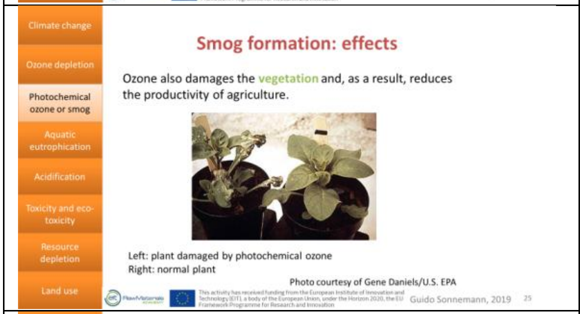
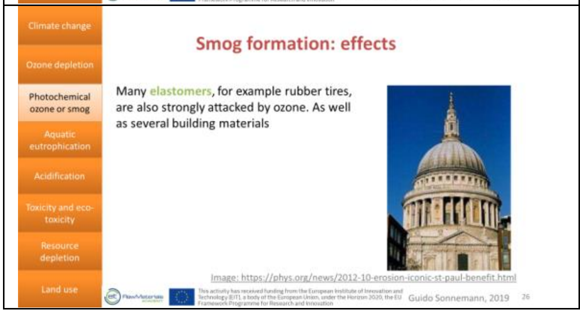


Here is the impact pathway of ozone depleting compounds. At the midpoint level, the ozone depleting potential is evaluated, which leads to damage on ecosystems and humans at the end-point level.

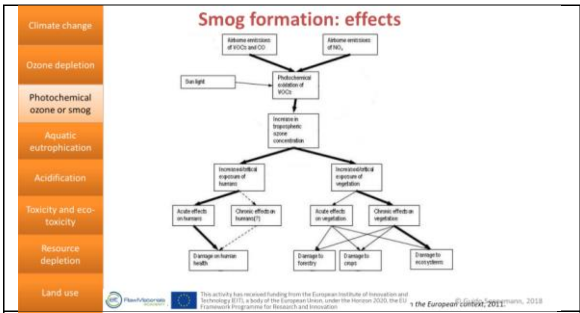




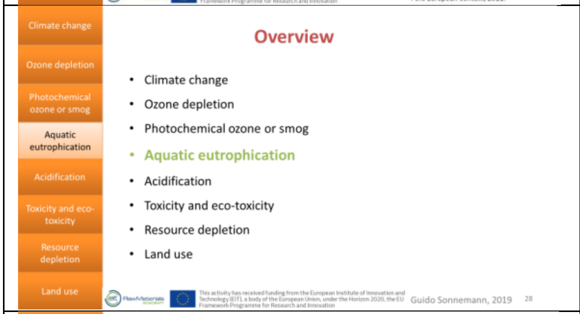
This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

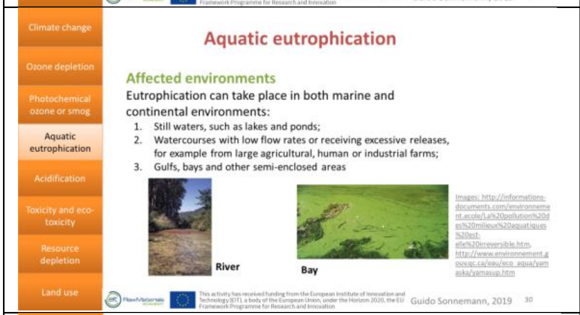
<table>
<tr>
<td>
</td>
<td>There are two distinct sources of smog, which are distinguished by "summer smog" and "winter smog".
Summer smog is caused by the photochemical formation of ozone from nitrogen oxides and VOCs.
Winter smog is caused by particulate matter, emitted for example by burning of coal.</td>
</tr>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>
</td>
<td></td>
</tr>
</table>

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

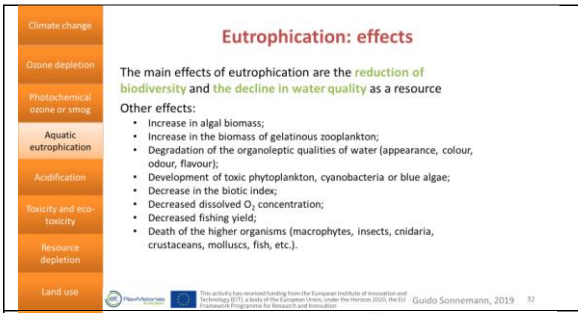


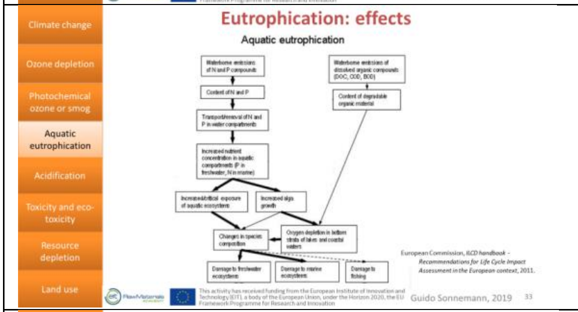
This is the impact pathway of the photochemical formation of ozone, or “summer smog”.
Note that the ozone formation is in a different location in the atmosphere than the protective ozone layer.



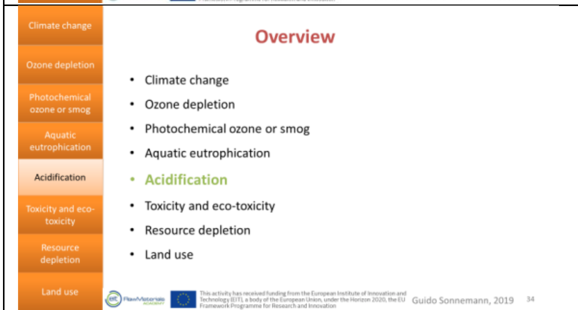


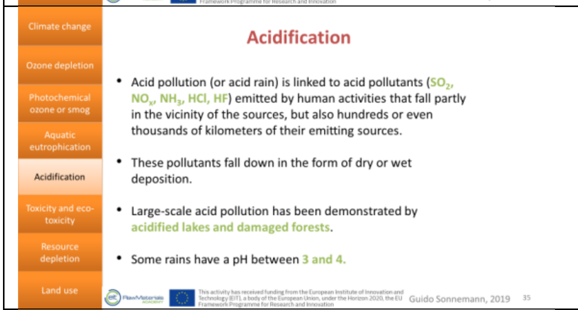
This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

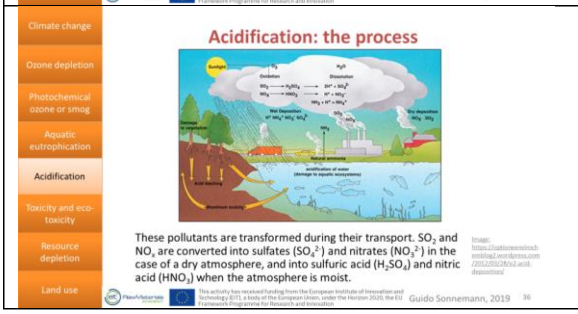




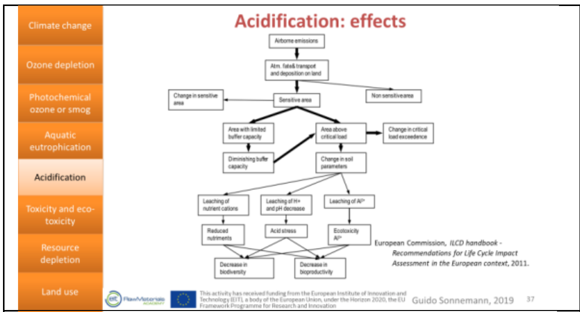
This is the impact pathway of aquatic eutrophication. Emissions of nitrogen and phosphor result in increased growth of algae, which decreases the availability of oxygen for other species, resulting in losses of species.



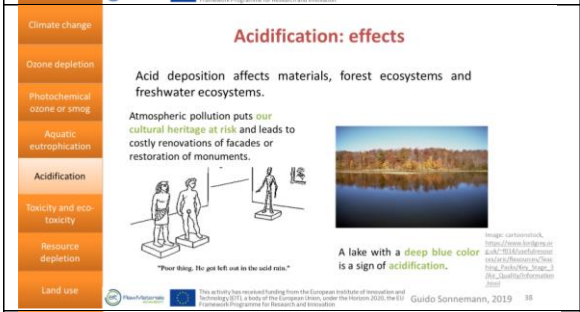


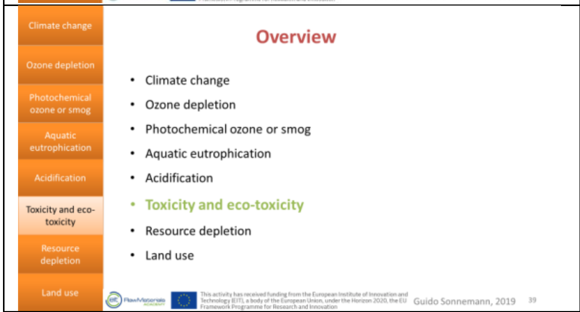


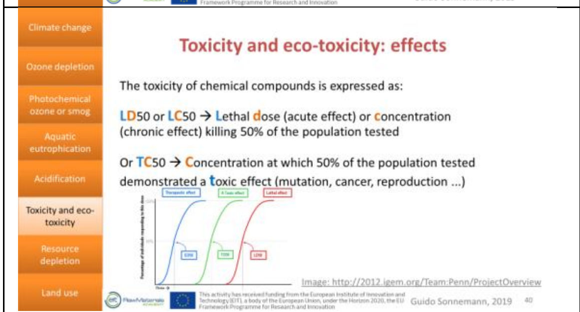
This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation



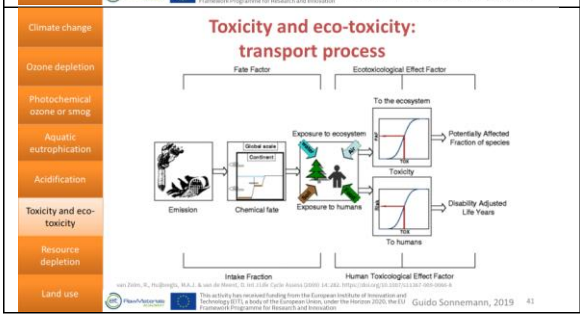
This is the impact pathway for acidification. Only when acid pollutants are transported via the processes in the previous slide to sensitive areas acidification takes place. This results in changes in the nutrient content or pH of the soil, or increased toxicity of the soil, affecting species locally.



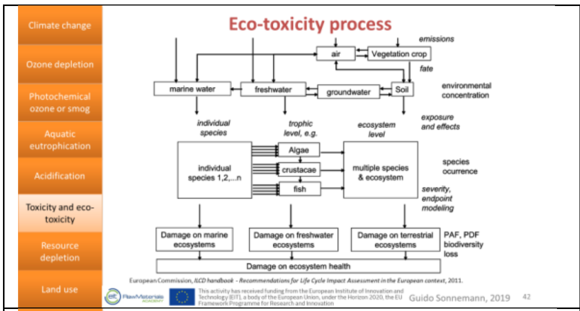
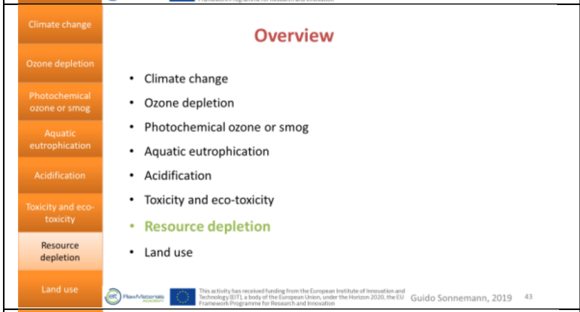
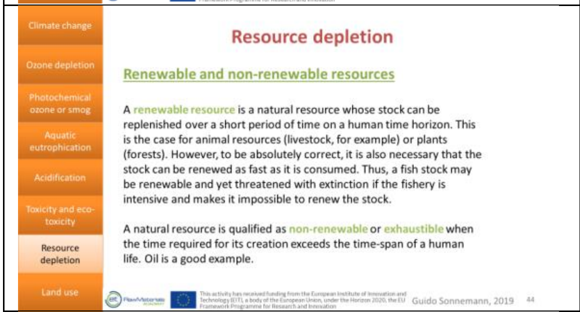
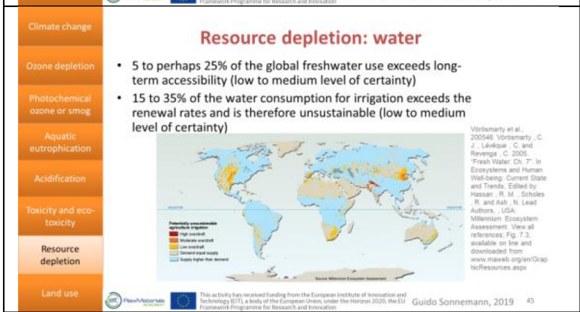
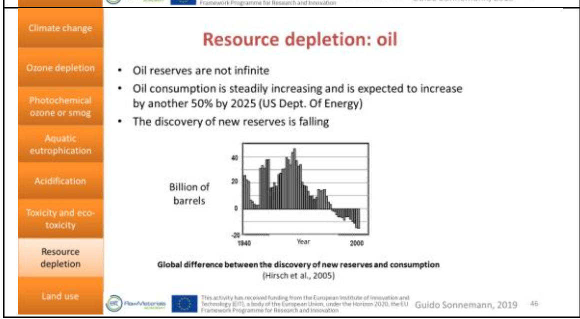




All environmental impacts are calculated via a fate factor and an effect factor. For toxicity, the fate factor represents the intake fraction, i.e. how much of a material is absorbed by humans or other species. The effect factor reflects the fraction of species that is affected for eco-toxicity. For human toxicity, it is calculated by the Disability Adjusted Life Years, or DALY.



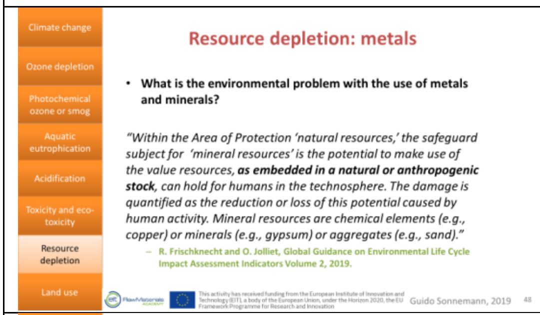
This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

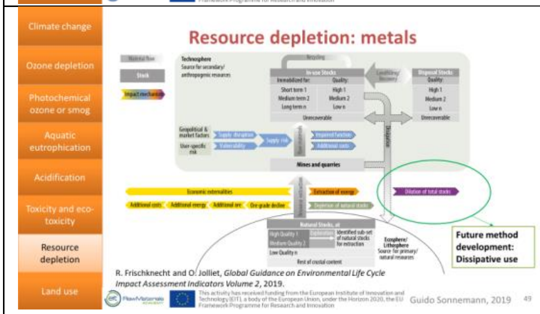
	PAF = Potentially Affected Fraction of species (PAF) PDF = Potentially Disappeared Fraction of species
	
	
	
	

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

<table>
<tr>
<td>


</td>
<td>
Many different impact assessment methods all evaluate something different with regard to metal use:

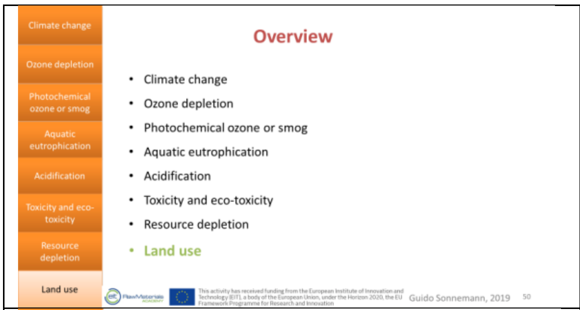
- Increased costs due to metal use
- Increased energy use
- Supply risks due to a high concentration of supply from politically instable countries
- Depletion of natural stocks
- Dissipative use is considered highly relevant in the impacts of resource use. It considers that no resource depletion takes place as long as the metal is still recoverable, for example by recycling. Only when a metal is used in an irrecoverable way, depletion takes place. However, there are currently no operational impact assessment methods that reflect the dissipative use of metals.
</td>
</tr>
<tr>
<td>


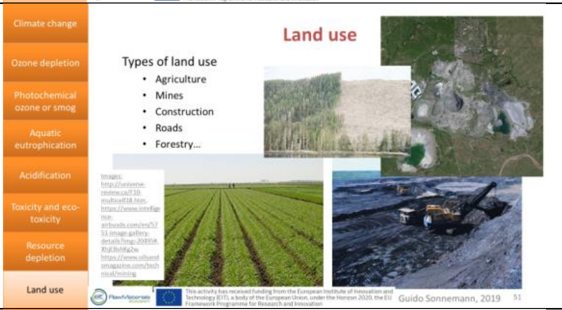
</td>
<td>
</td>
</tr>
<tr>
<td>


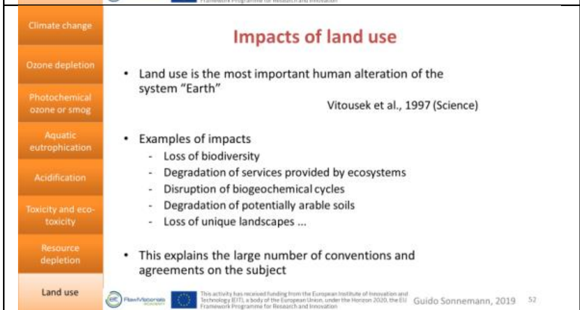
</td>
<td>
Many different impact assessment methods all evaluate something different with regard to metal use:

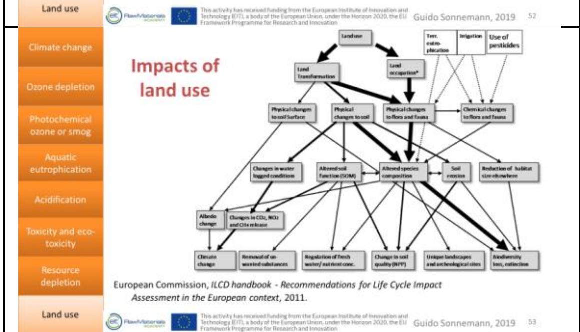
- Increased costs due to metal use
- Increased energy use
- Supply risks due to a high concentration of supply from politically instable countries
- Depletion of natural stocks
- Dissipative use is considered highly relevant in the impacts of resource use. It considers that no resource depletion takes place as long as the metal is still recoverable, for example by recycling. Only when a metal is used in an irrecoverable way, depletion takes place. However, there are currently no operational impact assessment methods that reflect the dissipative use of metals.
</td>
</tr>
</table>

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









Impacts of land use are very complex and important, as shown by this impact pathway. Land use can affect climate change, biodiversity, or how ecosystems function, and have therefore an impact on human health and ecosystems (not shown in this graph).

Take for example the life cycle of a wind turbine. The life cycle starts with raw material extraction. Raw materials are manufactured into components that make the wind turbine. The wind turbine is transported to its final location, where it is taken into use. During use, it will require maintenance to guarantee lifetime operation. Finally, some parts will be recycled, and some parts will be disposed of.

Each step in this life cycle will cause interactions with the environment: environmental exchanges. The most obvious step is the "raw material extraction" phase. Metals are taken from the earth's crust, water is used, and waste streams contain toxic elements, particulate emissions, or simply CO2 that ends up in the atmosphere, and in rivers, lakes, and the soil.

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

3 Examination Questions

What is the Greenhouse effect?
Answer 1: The name of climate change legislation that passed by the European commission
Answer 2: When the gasses in our atmosphere trap heat and block it from escaping our planet (correct)
Answer 3: When you paint your house green to become an environmentalist
Answer 4: When tomatoes grown under controlled greenhouse conditions ensuring a uniform size, shape and colour

What is the most common greenhouse gas?
Answer 1: Water vapour (correct)
Answer 2: Ozone
Answer 3: Carbon dioxide
Answer 4: The noble gases particularly Helium

Why is the ozone layer important?
Answer 1: It absorbs ultraviolet rays from the Sun that can cause cancer (correct)
Answer 2: It slows down global warming
Answer 3: It prevents respiratory diseases
Answer 4: It's not very important anymore

What is the name of the international treaty aiming to cut emissions of CFCs into the atmosphere (avoiding important ozone layer depletion)?
Answer 1: The Paris agreement – 2015
Answer 2: The Rio Earth summit – 1992
Answer 3: The Kyoto protocol – 1997
Answer 4: The Montreal protocol – 1987 (correct)

Eutrophication can take place…
Answer 1: in both marine and continental environments (correct)
Answer 2: in coastal areas
Answer 3: in urban areas during heat waves
Answer 4: in warm freshwater basins

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

What are the main sources of photochemical smog?
Answer 1: Ozone & CFC gases
Answer 2: Carbon dioxide & Nitrogen
Answer 3: Ammonia & Sulfur oxides (SO_x)
Answer 4: Nitrogen oxides (NO_x) & Particulate Matter (correct)

The impact pathway related to toxicity is the following…
Answer 1: Exposure – Severity – Effect – Concentration
Answer 2: Emission – Fate – Exposure – Effect (correct)
Answer 3: Fate – Exposure – Effect – Mortality
Answer 4: Dispersion – Exposure – Effect – Fate

What is 'resource depletion'?
Answer 1: Where humans use a resource at a rate that is not sustainable because it cannot be replenished fast enough. (correct)
Answer 2: Where humans use a resource at a rate that maintains the supply of the resource.
Answer 3: Where humans use a resource at a rate that is not sustainable because the behaviour of wildlife changes.
Answer 4: The use of any resource by humans.

Regarding water supply, which is the percentage of water, both fresh and easily accessible?
Answer 1: 0,014 % of the water volume on the Earth (correct)
Answer 2: 0,14 %
Answer 3: 1,4 %
Answer 4: 14 %

An ecological effect of land use is:
Answer 1: Biodiversity decrease (correct)
Answer 2: Impact on local and regional climate regulation (correct)
Answer 3: Change in the water cycle (correct)
Answer 4: Degradation of arable soils (erosion) (correct)

4 Acknowledgement and Authors

This teaching material was prepared by Guido Sonnemann, University of Bordeaux. The original course material was developed at CIRAIG Montreal (Canada) and provided by Ralph Rosenbaum, now at IRTA (Spain).

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:

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

Ruud Balkenende, TU Delft
Stefano Cucurachi, Uni Leiden
Andrea Gassmann, Fraunhofer IWKS
James Goddin, Granta Design
Dominique Guyonnet, BRGM
Heinrich Hofmann, EPFL
Alessandra Hool, ESM Foundation
Amund Loevik, Empa
David Peck, TU Delft
Armin Reller, ESM Foundation
Antti Roine, Outotec
Dieuwertje Schrijvers, University of Bordeaux
Guido Sonnemann, University of Bordeaux
Layla van Ellen, TU Delft
Tatiana Vakhitova, Granta Design
Ester van der Voet, Uni Leiden
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:
SusCritMat – Sustainable Management of Critical Raw Materials, funded by EIT RawMaterials, April 2017 – 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