Deliverable D4.2

Mapping of MICA methods to stakeholder questions

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Notice

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PURPOSE

Deliverable 4.2 *Mapping of MICA methods to stakeholder questions* assesses the methods as described in Deliverable 4.1 *Factsheets of Methods for Raw Material Intelligence* on their usefulness to help answering stakeholder questions as identified in Deliverable 2.1 *Stakeholder report: identification & analysis*.

EXECUTIVE SUMMARY

The MICA Raw Materials Intelligence Capacity Platform (MICA-RMICP) – also referred to as *the online platform* – aims to support stakeholders in the field of raw materials in answering their questions. This will be done by identifying accessible databases, but also by providing information on methods and tools by translating data into relevant information. MICA Work Package 4 (WP4) is dedicated to identifying, describing and making available information on those methods and tools. Deliverable 4.1 *Factsheets of Methods for Raw Material Intelligence* contains descriptions of a number of important methods from geology, industrial ecology and economics. This report, Deliverable 4.2 *Mapping of MICA methods to stakeholder questions*, assesses the usefulness of the methods to answer stakeholder questions. Deliverable 2.1 *Stakeholder report: identification & analysis* contains the results of a stakeholder analysis and identifies areas of interest for the different stakeholder groups in the field of raw materials. For D4.2, we have translated that information into 25 stakeholder questions, covering a wide array of topics within raw materials intelligence.

In an expert workshop, we asked researchers developing or working with the methods to indicate for which of the 25 questions "their" method could provide an answer. This input was the start of a broader analysis also covering literature. The results are presented in this report. The analysis also led to some recommendations for the MICA-RMICP and for the development of the raw materials intelligence field in general. Some of the most important recommendations are listed in Chapter 5 of this report.

In the list of methods, there are some more versatile methods that seem to contribute to many of the stakeholder questions. Among those are the core industrial ecology methods Material Flow Analysis, Life Cycle Assessment and Environmentally Extended Input Output Analysis. These methods come into play at any stakeholder question involving the supply chain, or of parts thereof, and form a valuable expansion of the geology-dominated domain of raw materials knowledge. On the other hand, there are also methods with a limited contribution to answering stakeholder questions. This does not mean those methods are futile. They can be very important, but only for very specific questions. Risk assessment and criticality assessment are examples of such methods.

Likewise, in the list of stakeholder questions, some seem to be easier to answer than others. For some stakeholder questions, none of the methods seems appropriate. One of the main reasons for that seems to be that not all stakeholder questions require methods – for some, the answer lies in the availability of data rather than methods. Such data (for example, a database of mining accidents) can also be part of a raw material intelligence system, but do not have to be linked to any specific method. Another reason is that for some areas of interest, such as social impact studies, there are no methods included in the D4.1 list. And finally, some questions really rely on standardised and comprehensive applications of methods. This means that methods are identified and available, but reliable outcomes are not. There are quite some examples of this in the area of secondary production.

Expanding raw materials information systems to include other databases, other types of information and especially other methods besides information on geological stocks and primary production makes it relevant for a larger range of stakeholders.

A promising endeavour could be to combine geological methods and Material Flow Analysis into one system to assess stocks and flows of both primary and secondary materials. This is essential information to support circular economy policies and strategies.

The information needed to perform criticality assessments can be put to a much wider use, i.e. for all purposes that require tracking and tracing of materials. Tracking conflict materials or keeping information all through the supply chain via product or material passports are examples.

A final recommendation is the use of forecasting and other types of scenarios to support raw material policies and strategies. No global scenarios exist for resource demand and supply and sustainability consequences. It is very important that such scenarios are generated. It requires a combined effort of methods of geology, industrial ecology and economy.

DELIVERABLE REPORT

1. Introduction

Raw materials supply the physical basis of our society. They are essential for the wellbeing and prosperity of our society. Resource and raw materials policies aim at continuing to supply society with sufficient resources, and to do so in a sustainable manner. This requires the effort of all stakeholders involved: the producers of raw materials, the manufacturers of products, the providers of services, the consumers and the managers of the waste that is generated at the end of the materials' life cycle.

For the effort of stakeholders to be fruitful, information is needed. The aim of the MICA project is to provide such an information base. MICA builds on a number of projects and initiatives. These projects concentrate mainly on data and databases on raw materials. While these data form the core of an information system, it is not sufficient information. For a continued, sustainable resource supply the data need to be put in context and related to different types of information in order to be relevant. Different methods exist to make this connection in various directions: the (future) availability of raw materials, but also the economic, environmental and social aspects of our extraction, production and use of raw materials. MICA provides extra intelligence compared to other projects among others by including methods for raw materials intelligence in the information system, in addition to data.

Deliverable 4.1 (van der Voet et al., 2016) contains factsheets of methods that provide essential information in answering stakeholder questions along the supply chain. In this deliverable, D4.2, these methods are confronted with stakeholder questions such as identified in WP2. Deliverable 2.1 (Erdmann et al., 2016) is a report of the stakeholder analysis and identifies topics of interest to the different stakeholder groups.

This report, D4.2, contains a mapping of the stakeholder questions on the methods as considered in D4.1. The work was kick-started by a workshop with experts on the different methods, and the analysis presented in this deliverable is based on their input and findings. Chapter 2 is a brief summary of the methods presented in D4.1. In Chapter 3, we distill 25 stakeholder questions out of the material presented in D2.1. Chapter 4 contains the mapping, and in Chapter 5 some conclusions and recommendations are presented.

2. Methods included in the MICA project

For mapping the applicability of methods to answer different kind of research questions the methods are used which are identified and described in D4.1 *Factsheets of Methods for Raw Materials Intelligence* (van der Voet *et al*., 2016). In D4.1, an extensive and referenced description is provided of these methods. Below, we present a brief summary of that information.

In the MICA project the following four categories of methods are identified that are important for putting data on raw materials in context:

1. Methods to identify and assess geological and anthropogenic (urban) stocks
2. Methods to assess society's metabolism and its environmental impacts
3. Methods to assess the economic aspects of the use of resources
4. Methods to forecast or estimate the future use of resources.

Table 1 shows the methods that have been selected to include in the MICA raw materials intelligence system. For each of the 4 methods in the categories a short description is given below Table 1.

Table 1 List of methods to be described in factsheets in MICA WP4.

1. Methods to identify and assess geological and anthropogenic (urban) stocks

- Geological mapping
- Remote sensing, e.g. regional geophysics
- Geochemical analysis, regional and local scale
- Ground investigation, including drilling (boreholes), trial pits, trenching, etc.
- Resource estimation, including:
    - For primary minerals – 3D models, deposit modelling, deposit assessment (feasibility studies), etc.
    - For secondary raw materials – compositional analysis of various stocks, e.g. municipal waste, mining waste, manufacturing stocks, etc.
- Material flow analysis (MFA)

2. Methods to assess society's metabolism and its environmental impacts

- Material flow accounting
- Material flow analysis (MFA) and substance flow analysis (SFA): accounting, static modelling and dynamic modelling
- Life cycle assessment (LCA), including attributional and consequential LCA, and including Life Cycle Sustainability Analysis (LCSA)
- Environmentally extended Input Output Analysis (EE-IOA)
- Risk Assessment, including Environmental Risk Assessment (RA and ERA)
- Footprinting at micro- meso- and macro-level

3. Methods to assess the economic aspects of the use of resources

- Cost benefit analysis (CBA)
- Life cycle costing (LCC)
- Input output analysis (IOA)
- Criticality assessment, including Herfindahl-Hirschmann-Index or other measures for producer country concentration, and World Governance Indicators, Failed States Index or other measures for stability
- Econometrics, includes causality tests and instrumental variables as well as time series analysis, structural Vector Autoregression models, dynamic and heterogeneous panel models, Bayesian

Networks, Structural Equation Modelling
- Computable equilibrium modelling; includes general equilibrium (CGE) modelling and dynamic stochastic general equilibrium (DSGE) modelling

4. Methods to forecast or estimate future use of resources (described in WP5)
- Bottom up forecasting
- Top down forecasting
- Forecasting based on the Cobweb theorem
- Back-casting

Ad 1. Methods to identify and assess geological and anthropogenic (urban) stocks
The relevance of methods to identify and assess stocks is obvious, and essential for questions related to the present and future availability of resources. In the MICA project, sources of secondary materials are considered as important as sources of primary materials and are therefore included explicitly. For stocks of primary materials, we rely on the well-established geological estimation methods.

Geological mapping is the process of creating a graphical representation, normally in two dimensions, as a birds-eye view of the rock types and other geological features. **Remote sensing** can be used to detect, identify and ultimately map hydrothermally altered rocks that are present on the earth's surface. Multi- and hyperspectral satellite and airborne data can be used for mineral exploration and mine waste mapping. **Geochemical mapping** provides a means of visualising spatial variations in the chemical composition of the Earth's surface. The chemical signature of any specific mineral deposit will reflect the commodities that it contains, and is likely to contrast significantly with that of surrounding rocks. Once a prospective area of mineralisation has been identified by regional mapping, geochemistry or remote sensing, further detailed **ground investigations** will be required to assess if a mineral resource is present and, if so, what the size and properties of the resource are. These ground investigations can consist of a range of different methods. **Mineral exploration** is the process of identifying mineral deposits of economic interest within the earth's crust, which if successful may lead to the extraction or mining of the deposit. **Mineral resource and reserve estimation** is the process of quantifying amounts of resources and reserves. *Mineral resources* are defined as natural concentrations of minerals or bodies of rock that are, or may become, of economic interest due to their inherent properties (for example the contained quantity of a metal [known as its 'grade'] or high crushing strength of a rock that makes it suitable for use as an aggregate [an assessment of the deposit's 'quality']). The mineral will also be present in sufficient quantity that there are reasonable prospects for eventual economic extraction. The part of a mineral resource which has been fully evaluated and is deemed commercially viable to work is called a *mineral reserve*. This process includes the assessment of several 'Modifying Factors' including (but not restricted to) mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors.

To some extent, the well-established geological estimation methods may also be relevant for secondary stocks. This could be the case for stocks on landfill sites, or underground hibernating stocks in for example pipes and cables. The assessment of urban stocks is a relatively new activity. Mainly the methods can be classified in two categories: the one is an inventory of stocks-in-use; the second is the use of dynamic Material Flow Analysis. Inventories are usually made by assessing amounts of relevant products and materials in use (buildings, infrastructure, electronics) and adding to that information on the content of the relevant materials. Such studies happen mostly at the level of cities and can be linked to municipal statistics. Material Flow Analysis is used in a number of studies to picture the urban metabolism, but these studies focus mostly on flows, ignoring the stocks. Dynamic MFA provides a picture of stock developments over time, if time series have been collected for a sufficiently long period. Such studies also exist at city level, but also at the national or even global level. Material Flow Analysis is a very versatile method, a core method for raw materials intelligence. It is really a method of the second category (society's metabolism) but can also be used in category 4, to estimate future demand and supply.

Ad 2. Methods to assess society's metabolism and its environmental impacts
Methods to describe society's metabolism and the consequent environmental impacts can be taken from the realm of industrial ecology. These methods usually consider larger parts of the life cycle of the raw materials, allowing for insights that may improve resource management. They include **Material Flow Accounting**, a method that describes the metabolism of national economies in terms of mass and is considered to be the physical counterpart of Gross domestic product (GDP). **Material Flow Modelling and Analysis**, already introduced under item 1, is also a tool of the second category, describing society's metabolism in terms of single materials or substances, having a narrow focus but allowing for much more detail in the description of flows, allowing to model stocks dynamics, and allowing to include environmental flows and stocks as well as those in society. **Risk assessment** is a well-known method that links local processes to environmental and health risks. It can be used to assess plants or locally defined operations. In contrast, **Life Cycle Assessment** is a method that strives to asses an encompassing spectrum of environmental impacts throughout the life cycle, at the micro-level of a single product or service. This method, though lacking in location specific risks, is essential for providing information throughout the supply chain. Presently LCA is put in the wider framework of Life Cycle Sustainability Analysis, among others aiming at upscaling the analysis to cover larger parts of society while keeping the life cycle perspective. **Footprinting** can be seen as a variant of LCA. **Environmentally extended Input Output Analysis** is, like Material Flow Accounting, a method operating at the level of national economies. It provides information of exchanges between sectors of the economy in monetary terms, but adds environmental extensions describing emissions to or extractions from the environment. The strong point of this method is the possibility to specify the supply chains at the national or even global level. At the same time, we should not expect any detailed information on resource flows to be correct.

Ad 3. Methods to assess the economic aspects of the use of resources
Economic aspects are very important as drivers for raw materials extraction. Market prices and the developments therein provide important information for investing in new mines. While it appears from trend information that for the major metals, the production has grown enormously at relatively constant prices, this is not true for minor metals and especially co- and by-product metals. Here, an increased demand but also an increased supply can cause prices to fluctuate wildly. For secondary production price developments are even more relevant and determine whether or not recycling activities even happen or not. For decisions of companies and investors, market price information is essential as a part of economic assessment methods such as **cost benefit analysis**, describing the economic sensibility of specific endeavours, and **life cycle costing**, specifying the costs over the life cycle as a mirror of the LCA environmental assessment.

While these methods have their relevance at the micro-level of individual decisions of companies and investors, there are also methods that have their relevance at the macro-level of sectors, national or even global economies. **Econometric and general equilibrium models** can be used to assess relevant economic events at the macro-level. These models to some extent can also be used to explore the future and provide forecasts that include economic mechanisms and feedback loops. While the relevance for resource use in general is apparent, these models usually are not very relevant for resources used in small quantities, such as minor and specialty metals. Also at the larger scale there is **Input Output Analysis (IOA)**. The Environmentally Extended variant is included under the methods in category 2, but IOA is basically an economic method that is relevant for describing intersectoral exchanges. Sometimes, Computable General Equilibrium (CGE) models have an input output model at their core, often one with a low granularity.

A specific method in this category is **criticality assessment**. This relatively new method is not yet mature – several approaches exist that are converging, but have not yet reached a standard. Criticality assessment is, however, very relevant, especially for minor and specialty metals. Although listed under economic methods, the approaches usually do not contain monetary information, but rather geological, geopolitical and technical information. Yet the relevance is of an economic nature and aims at protecting supply of essential materials with complications in the availability area. Therefore, criticality assessment is included in the methods of category 3.

Ad 4. Methods to forecast or estimate the future use of resources
The last category consists of forward looking methods. Forward looking methods somehow say something about the future. They often do so using scenarios. Scenario analysis can be used to visualize futures. This can be qualitative – developing storylines of potential futures that can be used for imagining what might happen – but it can also be quantitative, involving modeling of some kind. It can be used at all kinds of scale levels: companies, sectors, municipalities, and national and supranational governments. Best known globally are the United Nations (UN) scenarios on climate, energy and food. These start out from major driving forces, usually population and GDP, and include variants of governance that may

influence the variables of interest. In the energy and climate scenarios for example, the energy mix is different in different scenarios. In the area of resources and raw materials scenario development no such scenarios exist. Some first attempts are now being made, among others by the UN International Resource Panel. They estimate future demand for raw materials by using projections of population and GDP and correlations of those variables with material demand from the past, basically a **top-down approach**. Another option to generate demand scenarios for specific materials is to use **dynamic MFA in a bottom-up approach**. This approach starts from the idea of stock saturation: at a certain level of welfare, the stock of materials per capita does not grow anymore, and therefore the demand can also stabilize, or even be reduced to the level needed to keep up the stock. This approach is necessarily much more detailed and data intensive, as stock saturation must be specified at product (and not material) level. Factsheet for these methods were developed under WP5 in D5.1 (Falck et al., 2017).

In D4.1, these methods are described in detail. Attention is also given to the scope of their applications. This already focuses the task for D4.2. Especially for the industrial ecology methods, various overview studies have been done to position the methods relative to each other in goal, scope, system boundaries and relevance for answering questions from society (Wrisberg et al., 2002 is an early and very comprehensive example).

3. Stakeholder questions

Deliverable 2.1 contains an extensive stakeholder analysis. It identifies areas of interest for a great many different stakeholders in the field of raw materials. We have put ourselves in the place of a stakeholder that is interested in using the MICA online platform. Such a stakeholder will use the platform for a specific question rather than an area of interest. Therefore we have used the information contained in D2.1 to generate a number of very specific stakeholder questions. We have tried to cover a broad spectrum of questions, to obtain the best possible overview of the usefulness as well as the limitations for each of the methods. The list of questions has been communicated with the D2.1 team for a check. It is evident that these 25 questions do not cover the whole area of interest, but they do represent a number of crucial topics.

We have identified stakeholder questions in the following areas:

- Past and present availability of primary / secondary resources
- Past and present production of primary / secondary resources
- Criticality of resources
- Environmental impacts related to production and consumption of primary / secondary resources
- Social and economic impacts related to production and consumption of primary / secondary resources
- Prognoses for future demand, supply and impacts
- Trade, traceability
- Relevant policies: resource, environmental and social / economic policies

Table 2 shows the research questions that have been formulated to map questions to methods.

Table 2 List of questions used for mapping to methods.

Category	Question	No.
Past and present availability of primary / secondary resources	What is the estimated size of resources (economic, reserve base, ultimate earth crust) over the past 50 years, and where are they located?	1
	What is the estimated size of resources in urban stocks (i.e. stocks-in-use) over the past 50 years and where are they located?	2
Past and present production of primary / secondary resources	What was the extraction of raw materials over the past 50 years and where were they extracted?	3
	How much raw materials come available from discarded products yearly and what is the End of Life Recycling Rate?	4
Criticality of resources	What are supply threats of critical materials for local businesses in the EU?	5
	How can I, as a producer of electronics, identify conflict materials and exclude them from my production line?	6
Environmental impacts related to production and consumption of primary / secondary resources	What are the cradle-to-gate environmental impacts of primary and secondary raw materials production for the present world demand?	7

	What are risks of mining in different locations (land, sea, space)?	8
Social and economic impacts related to production and consumption of primary / secondary resources	What is the demographic breakdown of mining employees in different countries for different commodities in terms of gender, age, income, education?	9
	How many mine explosions have there been yearly during the past 25 years, where and how many casualties?	10
	How have prices of primary and secondary commodities changed over time?	11
	What are possible substitutes for material x in product y and how will this influence the environmental impacts of the product?	12
Prognoses for future demand, supply and impacts	How will the extraction of raw materials develop in the next 50 years?	13
	What are the environmental impacts of raw materials extraction of the future world demand?	14
	What will be the changes in energy use and efficiency of future mining and refining processes?	15
	What are promising future technologies to recover metals from waste and what are the costs?	16
Trade, traceability	What is the consumption of raw materials in Europe and in which country is the raw material extracted?	17
	What is de monetary added value of mining sector x and what are the accompanying environmental impacts?	18
Resource policies	What mix of policy instruments should be proposed to put a resource efficient circular economy in place?	19
	What are barriers towards a circular economy?	20
Environmental policies	How many cases of land grabbing are related to mining projects during the past 20 years?	21
	What recycling campaigns have been implemented in different countries during the past 25 years?	22
Social / economic policies	How much profit does a (mining) company make in each country and how much does it pay as taxes on those profits?	23
	What are the relative strengths and weaknesses of the national steel industry and how does this impact on national supply chains?	24
	Which aspects of the national steel industry are well-placed competitively over the short, medium and long-term to meet current and emerging demands domestically and globally?	25

4. Confronting stakeholder questions with methods

The stakeholder questions extracted out of D2.1 and the methods included in D4.1 have been confronted with each other in a workshop of experts in the area of one or more of the methods. The list of participants can be seen in Appendix A (page 27). These experts have a good view on what the methods can do, and also on the limitations of the methods. We have asked them to take a step back from their enthusiasm about the method that they have been working with successfully for some time now, to provide an objective assessment of the contribution of the method of their expertise to answering each of the stakeholder questions. The results of the expert workshop have been taken as the starting point of the exercise presented in this chapter.

The input we asked for from the experts was their assessment of what the method or methods of their expertise can contribute to when answering the stakeholder questions, in particular the 25 stakeholder questions that were identified in chapter 3. In addition, we asked the experts to:

- Identify gaps (missing methods as well as missing questions)
- Identify core purposes and auxiliary purposes of the methods of their expertise
- Share any additional insights from their side

Workshop participants were, based on their personal expertise, divided into four groups; corresponding to the four categories of methods we have distinguished:

- Geological methods
- Industrial ecology methods
- Economic methods
- Forward looking methods.

They were asked to fill in the matrix of stakeholder questions and methods for their category of methods as a group. This exercise was useful to get a consensus. In Appendix A, page 27, the four tables are presented, including the additions and comments made by each of the groups.

As a final step, the four tables have been combined into one; see Table 3

Table 3 Contribution of methods to answering stakeholder questions in the area of raw materials intelligence.

MICA Mineral Intelligence Capacity Analysis

WP4 workshop "Methods and Tools for Raw Materials Intelligence" **MICA workshop 27 September 2016**

Mapping research questions to methods and tools

	Methods to identify and assess geological and anthropogenic (urban) stocks					Methods to assess society's metabolism and its environmental impacts						Methods to assess the economic aspects of the use of resources						Methods to forecast or estimate future use of resources					
	Geological mapping	Remote sensing	Geochemical analysis	Ground investigation	Resource estimation	MFA - accounting	MFA - modelling	LCA	EE-IOA	RA and ERA	Footprinting	CBA	LCC	IOA	Criticality assessment	Econometrics	GEM and PEM	Forecasting (bottom up)	Forecasting (top-down)	Backcasting	Horizon scanning	Tech watch	Scenario storylines
1. What is the estimated size of resources (economic, reserve base, ultimate earth crust) over the past 50 years and where are they located?	Red	Red	Red	Red	Red	●	Red					●											
2. What is the estimated size of resources in urban stocks (i.e. stocks-in-use) over the past 50 years and where are they located?		●	●	Red	Red	Red	Red					●	●	●									
3. What was the extraction of raw materials over the past 50 years and where were they extracted?						Red								Red									
4. How much raw materials come available from discarded products yearly and what is the End of Life Recycling Rate?					●	●	●	●															
5. What are supply threats of critical materials for local businesses in the EU?					●										Red								
6. How can I, as a producer of electronics, identify conflict materials and exclude them from my production line?			Red						●		●			●	●								
7. What are the cradle-to-gate environmental impacts of primary and secondary raw materials production for the present world demand?	●	●	Red	Red		●		Red	Red		Red			Red									
8. What are risks of mining in different locations (land, sea, space)?	Red	Red	Red	Red			●	●	●	●	●												
9. What is the demographic breakdown of mining employees in different countries for different commodities in terms of gender, age, income, education?																							
10. How many mine explosions have there been yearly during the past 25 years, where and how many casualties?												●											
11. How have prices of primary and secondary commodities changed over time?					Red											Red							
12. What are possible substitutes for material x in product y and how will this influence the environmental impacts of the product?								Red	●									●			Red	Red	●
13. How will the extraction of raw materials develop in the next 50 years?					Red		Red							Red		Red	Red	Red	Red		●	●	
14. What are the environmental impacts of raw materials extraction of the future world demand?					Red		●	Red	●	●	●	●					●	Red	Red				●
15. What will be the changes in energy use and efficiency of future mining and refining processes?					Red		●	●						●		●		Red	Red		●	●	
16. What are promising future technologies to recover metals from waste and what are the costs?			●															●			Red	Red	●
17. What is the consumption of raw materials in Europe and in which country is the raw material extracted?						●	●		●						Red								
18. What is the monetary added value of mining sector x and what are the accompanying environmental impacts?								Red	Red	●					Red								
19. What mix of policy instruments should be proposed to put a resource efficient circular economy in place?						●	●	●	●	●						Red	Red						
20. What are barriers towards a circular economy?					Red							Red				Red	Red						
21. How many cases of land grabbing are related to mining projects during the past 20 years?																							
22. What recycling campaigns have been implemented in different countries during the past 25 years?																							
23. How much profit does a (mining) company make in each country and how much taxes does it pay on those profits?																							
24. What are the relative strengths and weaknesses of the national steel industry and how does this impact on national supply chains?					Red									Red			Red						
25. Which aspects of the national steel industry are well-placed competitively over the short, medium and long-term to meet current and emerging demands domestically and globally?														Red			Red						

Red: core method for this stakeholder question

Blue dot: can contribute to answering this stakeholder question

Below, we first discuss the different groups of methods and their contribution to answering stakeholder questions. Next, we take the angle of the stakeholder questions and see whether these can be answered with the set of methods included in D4.1. Finally we identify some issues of overall importance.

4.1 Relevance of the methods for stakeholder questions

Geological methods
Unsurprisingly, geological methods are important and even essential to answer questions related to the availability of geological stocks. More interesting is the fact that these methods according to the experts in the field can also contribute to identifying and estimating urban stocks. Ground investigation and resource estimation are regarded as core methods in that area. In contrast, urban mining inventories very much rely on statistical data related to production, trade and consumption. In the urban mining studies now starting up it could be a worthwhile addition to make a point of how geological methods can be used as well.

Geological methods also can answer stakeholder questions related to the environmental risks and impacts of mining. This use of methods, mainly in the remote sensing area, is also additional to the usual types of risk assessment. It may be very valuable to monitor mining sites in that way: substantial emissions to air or to the surface water are bound to show up, as are dam breaches and comparable accidents.

Geological methods appear, in the eyes of the people that use them, not to be linked so much with stakeholder questions on supply chains, on policy and on economics. The only exception is the method “resource estimation” which is rather a group of methods than a method in itself. The last method in this category, measuring inputs and outputs, is identified as being in the wrong category. It is part of MFA and therefore belongs in the second category.

Industrial ecology methods
It seems that industrial ecology methods are the most versatile methods of the lot. They have relevance for many of the stakeholder questions. It is therefore essential that these methods are emancipated in circles of professionals (researchers, mining companies, policy makers) and taken up as standard methods to support raw materials strategies or mineral policies. Especially the number of dots in the table, indicating that these methods have a contribution to make even if they do not provide the complete answer to a stakeholder question, is impressive. It suggests that stakeholder questions are often not straightforward but require different types of information for a satisfying answer.

Several of the industrial ecology methods are important for a variety of stakeholder questions, such as LCA and MFA. LCA is relevant for many questions that refer to the whole life cycle or value chain, providing an integrative framework over the life cycle stages. MFA links to the geological methods very comfortably, in the sense that flows and stocks of specific resources are the object of analysis. MFA focuses on flows and stocks in society, while the geological methods focus on the stocks in nature. As such, the two types of methods can be used in addition to each other, and MFA seems the ideal method to expand "classic" geological surveying with the urban mining component. In fact, as mentioned above, geological methods could be used to explore urban mines as well. Linking MFA and geological methods therefore seems to be a very good starting point for broadening the scope of the search for resources.

Some of the methods are more limited in their relevance for stakeholder questions. Although they can have an added value in many cases, they hardly ever turn out to be core methods. EE-IOA is an example of that, as is ERA, for quite different reasons. EE-IOA describes global value chains and therefore provides relevant input for trade and distribution related questions. However there are clear limitations with regard to the raw materials that can be included, for example minor and specialty metals will not be visible. ERA is a targeted tool that is only suitable to assess locational risks, and even those will not be covered completely. The information provided is therefore valuable but will hardly precisely respond to stakeholder questions.

Economic methods

Economics are very important for any activity related to raw materials. In all decisions made with regard to raw materials extraction, processing and use, economic aspects will play a role. Another reason that these methods are important is that – as can be seen in Table 3 – economic methods are the only ones that seem to be linked to stakeholder questions on policy. The reason for this is probably that several of methods are top-down, therefore, they encompass important parts of society which enables to assess the effects of certain policies on the whole economic system, and therefore identify side-effects as well as effectiveness.

A remarkable fact is that the IOA method is assessed quite differently by industrial ecologists and economists. Economists attribute possibilities to comment on future resource extraction to IOA, while industrial ecologists do not. As IOA is a static model, based on an accounting system, it seems that economists are a bit optimistic here. On the other hand, industrial ecologists seem to be overly pessimistic in not acknowledging the power of IOA to make a cross-sectoral comparison as asked for in stakeholder question 24; see Table 2. It may be a difference between the EE-IOA where sector classification is usually quite details and the "regular" IOA being linked to general equilibrium models that has a much less detailed resolution.

In the economic models category, there are also methods that have a wide contribution and more narrow methods. An example of the latter is cost-benefit analysis, which scores as a core method only for one question. That does not mean such methods are less valuable. It just means they are more restricted in their scope, therefore, for some questions they are spot-on while for others they are meaningless. Surprisingly, criticality methods – also methods with a dedicated scope and purpose – are viewed as useful for other types of stakeholder questions as well. The information needed for a criticality assessment apparently covers more territory.

A note made by the participants to the more encompassing models is that they should always be used in context and together with other information. Although this comment was not explicitly made in other groups, this is valuable advice for others as well.

Forward-looking methods
Forward-looking methods seemed the most difficult to link to the list of stakeholder questions. These methods have not been included in D4.1 but are part of WP5. During the meeting, participants have added three methods to the list: horizon scanning, tech watch and scenario analysis by storylines. These are qualitative methods, aiming at envisioning futures rather than assessing futures by numbers. Such methods can be very useful to create ideas and think through possibilities as well as barriers. It will be no surprise that these methods score highly on the future-oriented stakeholder questions. Back-casting is not once identified as a method, even contributing to answering even one of the stakeholder questions. According to the workshop participants, this is not because back-casting is a useless method but because there happened to be no question in the list of 25 that would require this method. Back-casting is useful when starting out from some desirable future state, to identify pathways towards that state.

It is surprising, however, that the forward looking methods are not mentioned more often at the stakeholder questions related to policies. Substitution is still within scope, but identifying barriers or assessing policy mixes certainly are within the scope of forecasting models. Scenarios and forecasting are considered essential tools in policy making at any scale level. Energy scenarios and climate scenarios play a valuable role in international climate negotiations. Resource scenarios presently do not exist, but they would be a very helpful input for any resource strategy or policy. The International Resource Panel is presently developing such scenarios, which have to be relevant for the sustainable development goals (SDGs) (see www.un.org/sustainabledevelopment/sustainable-development-goals/). Many of the SDGs can be translated into resource needs, and from there the step towards resource scenarios can be made. These methods can and must contribute more to policies, strategies and decision making on resources – their importance is expected to grow considerably over the next years.

4.2 Stakeholder questions answered by the methods

Looking at Table 3, it can be seen that for some questions, a variety of methods seem to be available. At the same time, there are questions that are not answered by any of the methods of the list. Workshop participants felt that not all questions were formulated with the required precision. This observation may be true but in practice, it will often happen that stakeholders have imprecise questions as well. Somehow, the MICA online platform will have to accommodate for that.

Past and present availability and production of primary / secondary resources
For estimating the availability of geological resources, a satisfactory suite of methods seems to be available. Data and methods to assess production of primary materials seem to be available as well. For secondary resources, the score of methods is lower. Urban mines have been investigated only sparsely, and secondary production data rely on incomplete and not standardized waste data. Estimates on End-of-Life (EoL) recycling rates are therefore also incomplete and have high uncertainty levels. Methods, especially related to MFA, are available, but have not been applied so widely as for primary production. In a society that has to rely more and more on secondary production, this gap needs to be filled, and can be filled. How this should be done and who should do it is still open. Geological surveys could take up this challenge, for example. As mentioned earlier, cooperation between geological methods and MFA seems very fruitful. This could be institutionalized as cooperation between geological surveys and national statistics offices.

Criticality of resources
For estimating resource criticality, a few dedicated methods are available. This is an area of ongoing research and development, but it seems that there is a good match between stakeholder questions and available methods. The underlying database may not be complete, however. Here, again, it is a question of data and standardization of application rather than a lack of methods. A much related topic is stakeholder questions regarding conflict materials. It could prove an excellent idea to include such aspects in criticality assessments.

Environmental impacts related to production and consumption of primary / secondary resources
An adequate number of methods are available to assess environmental impacts related to the production and consumption of resources. Some can be used for local aspects of individual stages in the life cycle, such as mining or waste management: some of the geological methods can contribute to that, as well as risk assessment methods. Others can be used to assess impacts over the life cycle: LCA is a method that is designed to do that at the micro-level, and EE-IOA can do it as well at the macro-level. Especially LCA is highly standardized and data are available that actually are provided by the metals and mining sector.

Social and economic impacts related to production and consumption of primary / secondary resources
For social impacts, no method appears to be available in the D4.1 list. We are not aware of any (standardized) methods to investigate such aspects. Nevertheless, such methods could be available and may fall outside our biased professional scope. Social impacts are certainly very relevant aspects, but seem a matter of data collection rather than methods. Certainly it would be very useful to have an overview of incidents related to mining or mining waste, or of worker conditions. Not methods, but procedures are needed for such things. With regard to economic aspects such as prices and costs, there are dedicated methods for that such as cost-benefit analysis, that are being used standardly by businesses before they enter any activity related to resource extraction and use. IOA is mentioned as a useful model to assess the contribution of certain sectors (therefore also the extractive sectors) to the

national income. Econometric and CGE models are rather used in a policy context to explore options for the future on their economy-wide impacts.

Prognoses for future demand, supply and impacts
Forecasting future demand, supply and impacts is not a standard activity at any scale level, although most actors in the supply chain engage in some kind of envisioning the future. Nevertheless, methods seem to be available to do quantitative forecasting. In this area, expertise has to be built up as it involves many different types of input. Geologists and mining companies look into the future to see how many "years" of a certain resource is still available in known deposits. Elaborate forecasting scenarios such as the energy scenarios and climate scenarios (IEA, 2010; UNEP, 2014) include economic driving forces and a variety of economic sectors, but do not include any other resources than energy carriers. Our analysis suggests that methods to be used in forecasting scenarios for raw materials are available. A combination is needed of geological, industrial ecological and economic methods and models, all combined in a forecasting approach. This is an upcoming challenge for resource-related research that probably will be taken up in the near future.

Trade, traceability
For some questions, it is necessary to be able to follow – and trace back – supply chains all over the world. From the survey, it appears that methods to do so are available. (EE-)IOA is mentioned, and also LCA, although this latter method is usually not explicit about time and place. LCA does seem to have the necessary level of detail to be relevant for resources of all kind. In IOA, it is likely that small scale commodities such as minor and specialty metals are invisible. For larger scale commodities like iron and steel, copper, fossil fuels or agricultural products IOA is an excellently suitable method to specify international supply chains. Although not mentioned by the workshop participants, geological methods can also be used to identify the origins of certain metals or gemstones, by determining their composition.

Relevant policies: resource, environmental and social / economic policies
Questions related to the existence of policies, their effectiveness and their side-effects remain largely unanswered by our list of methods. The only methods contributing to answering such questions are the economic methods. Partly, this may be due to the fact that – again – it seems to be a question of data rather than methods: simple inventories will do for questions related to the existence of recycling policies or cases of land grabbing. For another part, assessing the influence of policies is something related to forecasting and scenarios. And in some cases, workshop participants may have been too pessimistic. For example, a decomposition analysis performed on time series of input-output tables may uncover the influence of policies on changes in society's metabolism, and hybrid LCA can be used to spot rebound effects. Those are complicated endeavours, however, and are far from standardization.

4.3 General observations

Methods are a core part of the MICA project, and a significant addition to previous efforts in generating raw materials information systems. From the above, it is clear that the methods included in the factsheets of D4.1 are very important to use for a variety of stakeholder questions.

In the list of methods, there are some more versatile methods that seem to contribute to many of the stakeholder questions. Among those are the core industrial ecology methods MFA, LCA and EE-IOA. These methods come into play at any stakeholder question involving the supply chain, of parts thereof, and form a valuable expansion of the geology-dominated domain of raw materials knowledge. On the other hand, there are also methods with a limited contribution. This does not mean those methods are futile. They can be very important, but only for very specific questions. Risk assessment and criticality assessment are examples of such methods.

Likewise, in the list of stakeholder questions, some seem to be easier to answer than others. For some stakeholder questions, none of the methods seem appropriate. One of the main reasons for that seems to be that not all stakeholder questions require methods – for some, the answer lies in the availability of data rather than methods. Such data (for example, a database of mining accidents) can also be part of a raw material intelligence system, but do not have to be linked to any specific method. Another reason is that for some areas of interest, such as social impacts, there are no methods included in the D4.1 list. And finally, some questions really rely on standardised and comprehensive applications of methods. This means that methods are identified and available, but reliable outcomes are not. There are quite some examples of this in the area of secondary production.

5. Discussion, conclusions, recommendations

Resource intelligence is much more than geological surveying and geological data. This shows clearly from the wide variety of stakeholder areas of interest identified in WP2. In the MICA project, this is recognized by the inclusion of methods in WP4. From the above analysis, it appears that methods form a relevant addition, but the scope should be even wider. Stakeholder questions also refer to a wide range of data outside the usual realm, such as data on conflict materials, on mining accidents, on recycling rates, or on policies in place.

Stakeholder questions cover a wide range of topics, but also resource strategies and policies use a variety of disciplines and methods to support them. Geological methods are of course an essential part of that, but it appears that especially industrial ecology methods are relevant additions. These methods can be used to specify supply chains and allow for a life cycle perspective. They specify sustainability aspects and environmental impacts, and link those to supply chains. Last but not least, these methods add secondary stocks of materials (urban mines), recycling and secondary production of materials, which all are essential information for a circular economy.

Another essential element in supporting resource strategies and policies is forecasting. For resources, this area is still underdeveloped. Probably, the near future will see an effort in defining scenarios for resources in addition to the already existing scenarios for energy and climate. Many of the methods covered in D4.1 are essential for that: the geological methods to assess future availability of primary materials, MFA to do the same for secondary materials, IOA to capture trade flows all over the world, economic methods as driving forces for future demand and also for assessing the effectiveness of certain policies on future resource use, and finally LC(S)A to assess environmental impacts of future resource scenarios.

Based on the above, some recommendations for a MICA online platform can be made:

- So far, raw materials information systems focused on geological information and primary materials. Expanding this with other databases, other types of information and especially with other methods enhances the value of such a system and makes it relevant for a larger range of stakeholders.
- The MICA online platform wants to make the information available for users by specifying "flowsheets", pathways through the information in the system. It is important that such flowsheets do not become a straightjacket, and that plenty of flexibility is allowed in accessing the information. The above analysis shows that the precise formulation of questions is important, and that there may be varieties of the same question that require quite different information.
- Databases and methods are the core of the MICA online platform. Additional information may be important as well from a stakeholder point of view, for example, storing of information on "circumstantial" topics such as social aspects, presence of policies, isolated examples of good practice, occurrence of accidents etc. In addition, it may be useful to store references to actually conducted studies. Stakeholders not

willing or able to conduct their own investigations may benefit from the investigations of others.

The above analysis also leads to some recommendations for the field of raw material intelligence in general.

The information base for primary production is in much better shape than the information base for secondary production. Stakeholder questions often refer to secondary production, for example in view of efforts towards a circular economy. It appears that the suite of methods included in D4.1 is quite sufficient to generate such a database. However, applications fall short: inventories of material stocks in society and their dynamics are incidentally made but are not part of standardized and comprehensive efforts (Johansson et al., 2013). For the first time, a global material flow database is now available, covering time series from 1970 onwards (UNEP, 2016). It would be worthwhile to add information on material stocks at the global level.

It seems a promising direction to see whether geological methods and Material Flow Analysis can be combined into one system to assess both primary and secondary materials. Geological methods could be used also to detect and prospect urban mines, especially hibernating stocks and urban mines (Tanikawa et al., 2015; Zhang, 2013). Material flow analysis can link primary production to the system of flows and stocks in society. Modelling stock dynamics is a useful option to estimate how much materials enter the waste stage at a certain point in time. These materials then are available for secondary production. First efforts in this direction have been made (UNEP, 2010; Müller et al., 2014). In order to have the same value for stakeholders as the information on primary materials, this combined methodological system must be standardized and applied in the same manner all over the world. This suggests a link to statistical offices that compile data on production and trade (e.g. Eurostat, 2016). This is a huge effort, but a necessary one to create an information base for a circular economy.

Criticality assessments are a new addition to the methodological toolbox. Criticality assessments aim at giving a verdict on potential supply problems for materials. Most of the specific methods involved require a large amount of information to do so: not only geological assessments of scarcity, but also information on trade, ownership, supply risk elements related to governmental policies, and much more. This information can be used for other purposes as well, i.e. for all purposes that require tracking and tracing of materials. One example refers to material passports and product passports that retain supply chain information also for end users. This is valuable and even essential information for urban mining as well. Another example is the wish of stakeholders to know whether conflict materials are used in their products. This, too, could be enabled by using information out of criticality assessments.

A final recommendation is the use of forecasting and other types of scenarios to support raw material policies and strategies. Contrary to climate change and energy, no global scenarios exist for resource demand and supply and the sustainability consequences. It is very important that such scenarios are generated. It requires a combined effort of methods of geology, industrial ecology and economy. The UN International Resource Panel is setting some first steps in that direction (Elshkaki et al., 2016). It needs to be supported by the resource and raw materials research field. Hopefully, our community will take up that challenge.

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Appendix A: workshop materials

List of Participants in the MICA WP4 workshop "Methods and Tools for Raw Materials Intelligence" 27 September 2016, Brussels.

Name	First name	Organisation
Bleischwitz	Raimund	UCL-ISR
Bontoux	Laurent	European Commission
Deetman	Sebastiaan	Leiden University
Distelkamp	Martin	Osnabrück University
Domenech	Teresa	UCL-ISR
Falck	Eberhard	MinPol
Guyonnet	Dominique	BRGM
Hebestreit	Corina	Euromines
Huele	Ruben	Leiden University
Johansson	Jan	Lulea University
Keulen	Nynke	GEUS
Konrat Martins	Marco	LPRC
Lieber	Mirko	Vienna University
Manfredi	Simone	JRC
Müller	Daniel	NTNU
Peijnenburg	Willie	RIVM
Petavratzi	Evi	British Geological Survey
Schaffartzik	Anke	IFF Klagenfurt University
Tercero	Luis	Fraunhofer ISI
Thorsoe	Kisser	GEUS
Turner	David	EMPA
Van der Voet	Ester	Leiden University
Van Oers	Lauran	Leiden University

MICA expert workshop "Methods and Tools for Raw Materials Intelligence", 27 September, in Brussels.

Time: Tuesday, September 27, 10:00 – 16:00
Location: Metals Conference Centre, EUROMETAUX, 100 Rue du Duc, Brussels. The conference room is at the 5th floor.

Workshop Program

10:00 Introduction of MICA project (jointly with stakeholder workshop)
10:30 Introduction of the Raw Materials Intelligence system under development (jointly with stakeholder workshop)

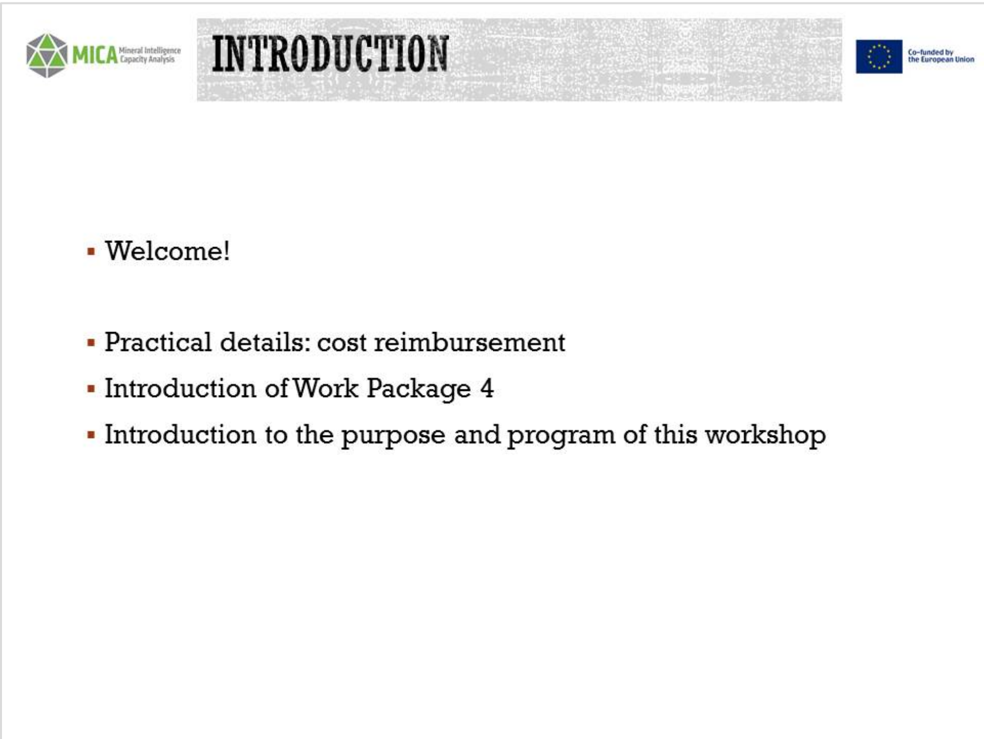
11:30 Introduction aims, purpose and procedure of expert workshop
11:50 Round table 2 minute statements by experts

12:30 Lunch

13:30 Mapping exercise: linking of methods and tools to stakeholder questions
15:00 Re-join stakeholder workshop and present results of mapping exercise.

16:00 End of workshop

The presentation given by the WP4 leader Ester van der Voet at the MICA expert workshop "Methods and Tools for Raw Materials Intelligence", 27 September, in Brussels.



WP4: METHODS

- MICA Work Package 4: Methods and Tools for Raw Materials Intelligence

- Objectives of WP4:

Inventory and Assessment of Tools and Methods for providing Expertise to Stakeholders on Mineral Intelligence

- Two starting points:
  - What do stakeholders want to know?
  - What tools and methods are available?

WP4: METHODS

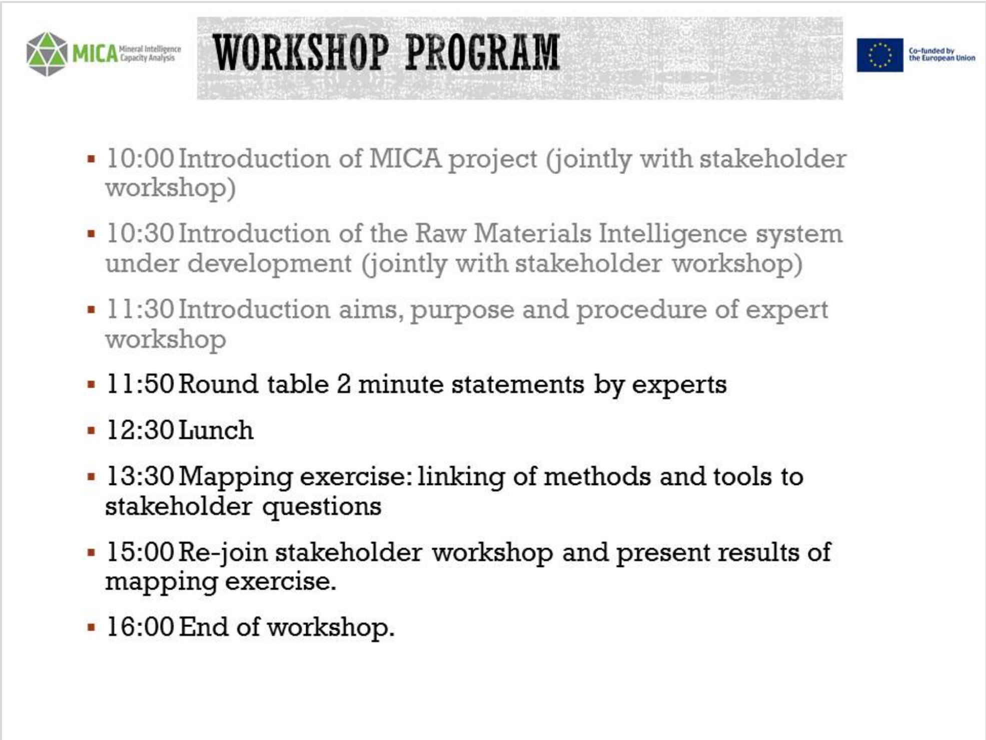
- What tools and methods are available?
- Overview in Deliverable 4.1, to be described in fact sheets
  - Main characteristics
  - Range of relevant applications
  - System boundaries
  - Data needs, data
  - Model used (if any)
- Classification in proposal: methods to
  - Identify and asses geological and urban mines
  - Assess society's metabolism and environmental impacts
  - Assess economic aspects
  - Forecast or estimate future resource supply and use
- List of methods you received is agreed on by WP4 participants
- Fact sheets of these methods will be reported.

PURPOSE OF THIS WORKSHOP

- Deliverable 4.2: mapping stakeholder information needs on methods.
- Partly jointly with the stakeholder workshop to facilitate dialogue
- You are experts on one or more of the methodologies in our list
- We would like your ideas on what these methods can contribute to the answering of stakeholder questions
- In addition, we would like to
  - Identify gaps (missing methods)
  - Identify gaps (missing questions)
  - Identify core purposes and auxiliary purposes of methods
  - Benefit from any additional insights from your side
- After the workshop, you may receive a request to review one of our fact sheets

WP4: METHODS

- What do stakeholders want to know about minerals?
- WP2 is about making an inventory of that
- In general:
  - Supply related questions
  - Functionality: what can it be used for?
  - Prices
  - Costs of extracting / purchasing / using
  - Environmental impacts
  - Social / humanitarian aspects
  - (Geo)political aspects
  - Others – supply chains, technology, …
- The list of questions you received are based on preliminary results of Deliverable 2.1


WORKSHOP PROGRAM
Co-funded by the European Union
▪ 10:00 Introduction of MICA project (jointly with stakeholder workshop)
▪ 10:30 Introduction of the Raw Materials Intelligence system under development (jointly with stakeholder workshop)
▪ 11:30 Introduction aims, purpose and procedure of expert workshop
▪ 11:50 Round table 2 minute statements by experts
▪ 12:30 Lunch
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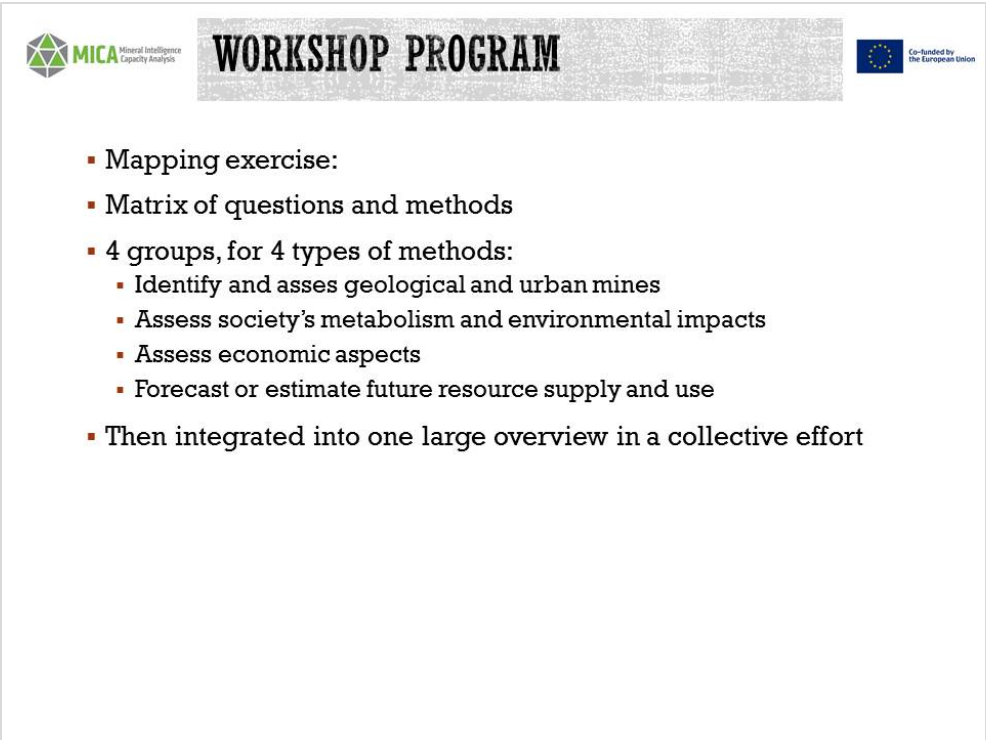
▪ 15:00 Re-join stakeholder workshop and present results of mapping exercise.
▪ 16:00 End of workshop.


WORKSHOP PROGRAM
Co-funded by the European Union
▪ Mapping exercise:
▪ Matrix of questions and methods
▪ 4 groups, for 4 types of methods:
▪ Identify and asses geological and urban mines
▪ Assess society's metabolism and environmental impacts
▪ Assess economic aspects
▪ Forecast or estimate future resource supply and use
▪ Then integrated into one large overview in a collective effort

ANY QUESTIONS?

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The results of the mapping exercise at the MICA expert workshop "Methods and Tools for Raw Materials Intelligence", 27 September, in Brussels.