Deliverable D3.4 & 4.4

Integrating data, methods and expert knowledge to inform mineral intelligence

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Notice

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PURPOSE

This report comprises a combined deliverable between WP3 and WP4. It explores how raw materials data (provided by WP3), methods (provided by WP4) and expert knowledge (delivered by the MICA consortium and external invited experts) can be integrated to deliver a pathway to an answer to a question or problem with a mineral (raw) material theme. It outlines the 'thinking process' that an expert would follow to reach to a result, with the aim to raise awareness about the considerations one should have in mind when seeking an answer to a specific raw material question. The ultimate goal of the proposed framework is to support stakeholders who miss the expert knowledge to develop independent thinking. The framework described corresponds to the development process of flowSheets in the MICA vocabulary. Several important remarks, regarding data and methods availability and gaps, as well as expert insight requirements are made throughout the report and they are explored in detail using stakeholder questions delivered to MICA as the starting point.

EXECUTIVE SUMMARY

Raw materials are fundamental to our everyday lives. Raw materials have been surrounding us since the beginning of human existence, but our understanding of their availability and potential is still incomplete. Population growth, economic and technological development relied on raw materials supply and it has grown rapidly in the past 200 years. Future demand is expected to rise as population growth will most likely continue and emerging economies are foreseen to develop further. At the same time environmental challenges, such as climate change influence the raw materials sector and concepts such as the circular economy, demand from us to rethink resource use. The interlinkages of the above, all related to raw materials, result to a wide range of questions often posed by stakeholders that are seeking for a response.

The work described in this report explores 21 questions, captured during the MICA stakeholder engagement stages, which relate to some of the aforementioned points. Five of these questions are discussed in detail. The report provides a methodology that can assist stakeholders interested in identifying answers to questions related to raw materials, to develop a thinking process and therefore support them in reaching an answer. The proposed methodology explores how data, methods and expert insight need to be combined in developing this 'thinking process' or, in MICA terminology, flowSheet.

The methodology appeared to be applicable to a variety of questions and it consists of the following steps:

- Translate the stakeholder question, which is by nature imprecise, into a more refined and demarcated question or set of questions that can be answered using raw materials data and methods.
- Identify data needs and databases that could provide the relevant information.
- Identify the need for application of one or more specific methods, to process the data into relevant information.

- Provide expert insight about gaps in data or/and methods, issues with existing methodologies, datasets, technical input, uncertainties or other information that are hard to capture by reading a report or methodology manual.
- Outline a series of steps that stakeholders could follow to guide them to an answer.

A fundamental conclusion of this work is that all stakeholders, both those asking the questions and those responding to them, need to have a clear understanding of the steps involved and the associated tools that are available to respond to such questions. Raising awareness and understanding among all the parties involved, based on clear and transparent communication, is paramount.

DELIVERABLE REPORT

1. Introduction

Any research, no matter what the discipline, arises from a question that requires an answer. Questions on the same topic or area of interest may require very different answers and the use of different combinations of data, methods and expert insight. The way a question is phrased is crucial. 'What', 'where', 'how long' and 'why' questions will have to be approached separately and will require different answers. 'Who is asking the question' is equally important and has to be taken into consideration when formulating a response.

For example, if we hypothesise that the topic of 'European deposits of copper' is of interest, then some potential questions that may be posed by stakeholders on this topic are:

1. What are the geological settings of copper deposits found in Europe?
2. Where are European copper deposits located and how large are they?
3. Will copper become a critical metal for the EU by 2030?
4. Why is it projected that the future demand for copper in Europe will increase rapidly?

All of the above questions relate to European copper deposits, but in order to answer them, different datasets and methods should be employed. For example, question 1 will require the interrogation of geological maps and related information produced by geological surveys, as well as the review of scientific literature associated with copper deposits in Europe, deposit models and so on. Question 2 will also require access to maps, both geological and topographic, and to data on deposit size that may be collated by geological surveys or specific government departments, or which might be available from company reports. Answers to Question 3 and 4 require future predictions that will depend on the use of a variety of datasets and methods (e.g. forecasting and uncertainty methods).

New questions are continually posed to the research community: these emanate from new projects, from decision makers, from the public and from the research community itself. Ultimately, how well a question is phrased will define how well a response, or a project, or research is developed. It is therefore crucial that substantial thinking is put into formulating and refining questions in the first place to ensure that the response provided is appropriate.

The aim of the flowSheet development explained in this document is to facilitate and clarify the process of question definition and response. Stakeholders often have the desire to get answers to questions they are concerned with, but they do not always know the best way to approach them. They are missing the expert knowledge, but also the independent thinking. This report provides a methodology that can assist stakeholders interested in identifying answers to questions, simple or complicated, related to raw materials, to develop a thinking process (follow a methodology) and therefore support them in reaching an answer. The proposed methodology explores how data, methods and expert insight need to be combined in developing this 'thinking process' or, in MICA terminology, flowSheet. The development of the methodology involved the identification of 21 questions linked to different stakeholder needs and the subsequent formulation of flowSheets by a multidisciplinary team.

2. Methodology for flowSheet development

2.1 Approach

A flowSheet is a recipe to answer a specific research question. Ideally the flowSheet contains:

a) the ingredients, such as data, methods, and knowledge, and;
b) the procedure, the sequence or flow of information processing.

Additional information about the definition of the MICA flowSheets is included in the deliverable report D3.3 (Petavratzi, 2017).

The process of developing flowSheets is based on a framework developed in the joint MICA WP3/WP4 workshop held in Paris in June 2017 (MICA, 2017). Since this workshop, the framework has been enhanced and a template was designed to help to redefine the question into specific sub-questions using predefined keywords. The predefined keywords align as much as possible to the hierarchy of the main MICA ontology and the transverse MICA ontologies, see section 2.3.

For each of these questions, one or more flowSheets were developed. This is not a straightforward exercise but requires expert input and in most cases it can only be done by an interdisciplinary group of professionals. To develop the flowSheets from the questions a group of partners from the consortium worked together, whereas during the WP3/WP4 MICA workshop in Paris several external stakeholders also contributed to this task. The group included experts from different fields, including geological sciences, social and environmental sciences, foresight studies and information technology. The participants can be seen in Table 1.

Table 1 List of project participants in the MICA WP3 and WP4 workshop "FlowSheets, Data and Methods for Raw Materials Intelligence" 10-11October 2017, Leiden.

Name	First name	Organisation
Huele	Ruben	Leiden University
Van der Voet	Ester	Leiden University
Van Oers	Lauran	Leiden University
Petavratzi	Evi	British Geological Survey
Gunn	Gus	British Geological Survey
Cassard	Daniel	Bureau de Recherches Géologiques et Minières
Tertre	Francois	Bureau de Recherches Géologiques et Minières
Faigen (Machacek)	Erika	Geological Survey of Denmark and Greenland
Konrat	Marco	La Palma Research Centre for Future Studies

To test the framework and get a shared understanding of how to fill in the template and derive a flowSheet two research questions were first discussed by the group as a whole. After that the group was split into two multidisciplinary teams, in order to be able to cover all 21 questions.

2.2 Research Questions

In the MICA project substantial effort has been put into the identification of the needs of different stakeholders, including not just the primary and secondary raw materials sectors, but also manufacturers, end-users and policy makers. In WP2 an inventory of questions raised by different stakeholder groups was made (Erdmann et al., 2016). WP3 identified data that are relevant to the different questions or topics of concern raised (Petavratzi & Brown, 2017). In WP4, the same was done for methods that process data (Van der Voet et al., 2016). These methods are mapped to stakeholder questions (Van der Voet et al., 2017). Several workshops were held during the course of the MICA project that also captured stakeholder needs.

The stakeholder questions used for the development of flowSheets are based on the various activities mentioned above. They are shown in Table 2.

Table 2 Research questions derived from WP2.

No	Proposed Questions	MICA Domain	Concept Level 1
1	What is the mineral endowment of commodity x in Europe?	D1 Primary mineral resources	1.4 Mineral/ore deposit; 1.5 Mineral Exploration
2	What is the overall timeframe and cost associated with bringing a commodity to a user?	D1 Primary mineral resources	1.6 Preliminary Economic Assessment
3	What is the recycling and recovery level of IT and technology equipment?	D2 Secondary Mineral Resources	2.1 Material recovery
4	How much waste is generated by mining commodity x at location y and what is its composition	D2 Secondary Mineral Resources	2.3 Waste
5	To what degree are we already circular regarding material x?	D2 Secondary Mineral Resources	2.2 Stocks/ Materials
6	What are the Technology Readiness Levels (TRLs) of recycling technology for new/emerging materials?	D2 Secondary Mineral Resources	2.1 Material recovery
7	What is the estimated size of resources in urban stocks (i.e. stocks-in-use) of CRMs over the past 50 years and where are they located?	D2 Secondary Mineral Resources	2.2 Stocks/Materials
8	How much of commodity x will be produced in year x?	D4 Raw Materials Economics	4.4 Demand; 4.6 Supply
9	What is the supply chain of commodity x OR product x and who is it involved?	D4 Raw Materials Economics	4.6 Supply
10	How does trade influence security of supply?	D4 Raw Materials Economics	4.6 Supply
11	Should the EU invest/investigate in getting more mines in Europe?	D4 Raw Materials Economics	4.4 Demand; 4.6 Supply; 4.5 Investment
12	What is the estimated size of resources (economic, reserve base, ultimate earth crust) over the past 50 years and where are they located?	D4 Raw Materials Economics & D1 Primary Mineral Resources	4.4 Demand; 4.6 Supply ; 1.5 Mineral Exploration

13	What repair/remanufacture/reuse legislation is in place?	D5 Raw Materials Policy & Legal Framework	5.1 Circular economy
14	How diverse are mineral policies across the globe and how do they influence mineral extraction?	D5 Raw Materials Policy & Legal Framework	5.5 Mineral policy/strategy
15	How does a decision to restrict a material (e.g. REACH) affect the industry using that material?	D5 Raw Materials Policy & Legal Framework	5.3 Environmental legislation
16	How may designation areas (i.e national parks) restrict exploration/extraction of commodity x in region/country x?	D5 Raw Materials Policy and Legal Framework	5.4 Land use policy
17	What are the cradle-to-grave / cradle-to-gate environmental impacts of using a specific resource/ raw material?	D6 Sustainability of Raw Materials	6.3 Impacts over the life cycle
18	What are risks of mining in different locations (land, sea, space)?	D6 Sustainability of Raw Materials	6.2 Impacts of specific processes/plants 6.3 Impacts over the life cycle
19	What are possible substitutes for material x in product y and how will this influence the environmental impacts of the product?	D6 Sustainability of Raw Materials	6.3 Impacts over the life cycle
20	What are the environmental impacts of recycling versus mining for commodity x?	D6 Sustainability of Raw Materials	6.3 Impacts over the life cycle
21	How can I find out the raw material composition and content of my product?	D6 Sustainability of Raw Materials	6.5 Resource Efficiency

2.3 Template to classify and specify research questions

A template was designed to help to redefine the question into specific sub-questions using predefined keywords (the keywords are mostly taken from the MICA ontologies – see Appendix 8.1). Part of the template is used to identify the databases and methods that are needed to answer the sequence of sub-questions. A flowSheet is a graphical presentation of the iterative procedure of input data-method-knowledge and output data, or as mentioned earlier a 'recipe' to reach an answer.

The steps in drafting flowSheets are:

1. Identify the type of the question e.g. 'what', 'where', 'who' etc.
2. Set boundary conditions to classify the question in terms of key words: e.g. commodity, process chain, temporal and spatial characteristics (Table 3)
3. Translate the imprecise stakeholder question into an exact research question and define relevant sub-questions, including assumptions and remarks
4. Define data needs and identify data gaps
5. Define methods needs and identify methods gaps
6. Provide additional expert insight and information
7. Draft the graphical representation of the flowSheet.

The flowSheet explains the thinking process or knowledge chain by outlining the steps required to guide a stakeholder through the 'seeking evidence' process. The flowSheet diagram is a visualisation of the process, using squares for data and circles for methods. The knowledge and insight lies in the way these are combined together.

The keywords are chosen from predefined terms used in the MICA ontology (Appendix 8.1). They are used to clarify the scope of the original question and break it down into relevant sub-questions. In Table 3 a short description of the classification of the scope of the questions is given.

Table 3 Classification of the research question using boundary conditions (see also Appendix 8.1).

COMMODITIES	The term refers to a range of items, including minerals, metals, semi-products, final products and wastes that are traded in standardized forms.
PROCESS_ CHAIN(activity)	A particular stage in the cradle to grave process chain, from extraction of ores to production, manufacture, use and waste disposal of the final end-of-life product.
IMPACTS	The term refers to the pillars of sustainability: environmental, social and economic impacts.
SPATIAL(activity)	The term activity refers to the economic activity (i.e. process, industry). The geographical coverage may imply processes all over the world, within a single country or a process within an identified corporation. The spatial coverage of the activities should be specified. These may include activities on a global scale (e.g. processes related to a process chain of a product, which might be located all over the world as in Life Cycle Assessment) or a very local installation in a corporation (e.g. local activity and impacts as assessed in a Risk Assessment).
SPATIAL(impact)	The term impact refers to the effect the economic activity has on environmental, economic and/or social aspects. The geographical coverage of the effects should be specified. They may imply effects on a global scale (e.g. global warming or many regional effects related to activities scattered all over the world as in Life Cycle Assessment) or a very local effect caused by an identified installation as in Risk Assessment.
TEMPORAL(activity)	The time period of the economic activity should be specified, either historical, present or future.
TEMPORAL(impact)	The time period of the impact should be specified, either historical, present or future impacts.
FLOWS	To which flows between economic activities and the environment is the research question referring, Import, Export, Production, Consumption, Waste, Emission?
STOCKS	Is the research question referring to stocks? If yes, which types of stocks: lithosphere, anthroposphere or all?

3. Methodology application and results

In this report the development of flowSheets for 5 research questions is described in more detail. The draft completed templates and flowSheets for all 21 research questions are given in Appendix 8.2.

In this section the different steps for compiling the flowSheets are described. Knowledge gaps are also identified which will help to define data and method strategies for future mineral intelligence.

The five questions were selected on the basis of the following criteria (Table 4):

1. A question for each MICA domain should be assessed. Please note that there are no questions in Table 2 associated with domain D3 Industrial Processing and Transformation
2. Relatively simple 'look up' questions were not selected. The aim of this work was to attempt to develop flowSheets for more complex questions.
3. Questions that were not assessed clearly during the workshop and included incomplete templates and flowSheets were excluded from the analysis.

Table 4 Research questions for which the detailed development of flowSheets is described.

Domain	Concept	No	Research Question
D1 Primary mineral resources	1.4 Mineral/ore deposit; 1.5 Mineral Exploration	1	What is the mineral endowment of commodity x in Europe?
D2 Secondary Mineral Resources	2.1 Material recovery	3	What is the recycling and recovery level of IT and technology equipment?
D4 Raw Materials Economics	4.6 Supply	10	How does trade influence security of supply?
D5 Raw Materials Policy and Legal Framework	5.4 Land use policy	16	How may designation areas (i.e national parks) restrict exploration/extraction of commodity x in region/country y?
D6 Sustainability of Raw Materials	6.3 Impacts over the life cycle	20	What are the environmental impacts of recycling versus mining for commodity x?

3.1 Question 1: What is the mineral endowment of commodity x in Europe?

Step 1: Identify the type of question

This is a ‘what’ question asking to quantify the endowment of a specified commodity in Europe.

Step 2: Classify the question

In this step any boundary conditions defined in the original question are outlined.

Scope	Keywords	Comments
COMMODITIES:	ALL	commodity to be specified
PROCESS_ CHAIN(activity):	Exploration	
IMPACTS:	n.a.	
SPATIAL(activity):	Continental Level	Europe
SPATIAL(impact):	n.a.	
TEMPORAL(activity):	Present	
TEMPORAL(impact):	n.a.	
FLOWS:	n.a.	
STOCKS:	Lithosphere	

Step 3: (I) Specify the question

The original question is defined in general terms. It should state which type of commodity should be analysed, as different data will relate to different commodities. For the purpose of this work, we specify the commodity to be copper. The original question is therefore re-phrased as:

What is the total mineral endowment of *copper* in Europe?

The term mineral endowment is not widely used in economic geology and there is no consensus on its definition. In general the mineral endowment of an area refers to the total amount of a particular metal or mineral in that area which has certain physical characteristics such as quality, size and depth (INSPIRE, 2013). Endowment usually includes resources but unlike the latter it does not imply potential for economic extraction from that area. However, the question that will be of most interest to all stakeholders does concern that part of the mineral endowment that might actually have some likelihood of economic extraction at some time in the future. Therefore, for the purpose of answering this research question, the mineral endowment is considered to comprise the sum of the undiscovered and discovered mineral resources within the area (see USGS, 2017, for definitions of resource and reserve terminology). The mineral reserve, which is that part of an identified or discovered resource that could be economically extracted at the time of the assessment, is normally included within the discovered resources category.

Mineral occurrences and deposits comprise the physical entities in the ground that may include a resource and/or a reserve. For the purposes of calculating the mineral endowment the known discovered resources and reserves within deposits and occurrences are summed. These are then added to the undiscovered resources to provide an estimate of mineral endowment. For some minerals and metals estimates of discovered resources, including reserves, may be available for some areas or countries. However, estimation of undiscovered resources is far more challenging and very few estimates exist for a few commodities in a few areas. Assuming that the question refers to potential endowment of undiscovered resources much more research and exploration is needed before this question can be answered.

For the purposes of this analysis the term is assumed to refer to geological stocks only.

Step 3: (II) Define relevant sub-questions

From the above, we identified two sub-questions:

a) What is the size of the identified resources of copper in Europe?
b) What is the size of the undiscovered resources of copper in Europe?

Step 4: Define data needs and identify data gaps

In order to answer the first question about identified resources there are some databases and reports in which identified resources of commodity x, e.g. copper, are reported. These include:

- Minerals4EU[1]
- ProMine[2]
- FODD (Fennoscandia Mineral Deposits Database)[3]
- EURare[4]
- SNL
- USGS commodity profiles[5]

All of the publicly available databases and data sources are accessible through the MICA platform and in that sense suitable data sources do exist. However, these data sources do not necessarily provide reliable answers to the research question posed: there may be data gaps for certain commodities in individual countries, while for some commodities no resource or reserve estimates are available at either a national or deposit scale. Further, some databases are not in the public domain and are only accessible through payment of a subscription (e.g. SNL data).

There are no databases available to answer the second question about undiscovered resources. A small number of individual studies focussed on a few commodities have been published. However, these assessments are complex technical tasks that depend on the availability of a wide range of geoscientific data and on suitable expertise for its analysis and interpretation. The completed studies apply only to a restricted range of deposit types and thus do not provide estimates for the *total* undiscovered resource of a particular commodity. The methodology for estimating undiscovered mineral resources was pioneered by USGS who applied it to copper in a single deposit type (porphyry copper deposits) in the Andes (Cun-

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1 EU Mineral intelligence network structure delivering a web portal, a European Minerals Yearbook and foresight studies www.minerals4eu.eu/

2 Nano-particle products from new mineral resources in Europe http://promine.gtk.fi/

3 Fennoscandia Mineral Deposits Database http://gtkdata.gtk.fi/fmd/

4 Development of a sustainable exploitation scheme for Europe's Rare Earth ore deposits www.eurare.eu/

5 USGS commodity profiles https://minerals.usgs.gov/minerals/pubs/mcs/

ningham et al., 2008). This was subsequently expanded to provide a global assessment of undiscovered copper resources in the two most commercially important deposit types, porphyry copper and sediment-hosted copper deposits (Johnson et al., 2014). An in-depth expert analysis of copper's future resources took the USGS results and added to them estimates for copper in other deposit types and copper that had already been mined to produce an estimate of the total global endowment of copper (Singer, 2017). In 2009, GEUS initiated mineral resource assessments within the USGS-led Global Mineral Resource Assessment Program (Briskey et al., 2003; Singer et al., 1993) and conducted independent assessments on various metals in 03deposits in Greenland (Stensgaard et al., 2013). GTK also applied the USGS method to determine the undiscovered mineral resources of several metals in various deposit types in Finland (Kalevi et al., 2017).

Step 5: Define methods needs and identify methods gaps

To answer the first question no methods are needed. Information, such as it is, can be looked up in databases and requires no further processing.

To quantify the undiscovered resources a wide range of geological (and geophysical) methods is needed to identify and assess geological stocks. The fundamental datasets are derived from:

- Geological mapping
- Remote sensing
- Geochemical analysis
- Ground investigations, such as trenching and drilling
- Resource estimation
- Mineral deposit research to characterize grade and tonnage of various deposit types and to estimate the probability of their occurrence within a particular area.

There are no real method gaps to identify and assess geological stocks. The methods for estimating known resources and reserves are well established although they are not harmonised across the globe. The methodology for the estimation of undiscovered resources is immature and has so far been applied to a very small number of commodities in areas where the geology is well known. Consequently it is not possible to provide estimates of undiscovered mineral resources for most commodities in most parts of the world.

However, in the context of a circular economy the methods used for assessing geological stocks could be made applicable to assess anthropogenic stocks too. For this purpose some development of new or adaptations of the existing methods could be helpful.

Step 6: Expert knowledge and conclusions

- There is a need for clear globally harmonised definitions, e.g. endowment, resource, deposit, reserve, undiscovered resources etc.
- The methods for estimating identified resources and reserves are well established. However, there is a need for clear globally harmonised methods. In theory, the iden-

tified resources and reserves of Europe for a specified commodity (e.g. copper) could be calculated by adding together individual resources and reserves estimates measured at deposit or national level. However, in practice, the data available are not harmonised, hence this step cannot be undertaken without input from experts.

- USGS has developed a methodology to estimate undiscovered resources. However, it is relatively immature and requires large amounts of geological data and considerable expert knowledge of mineral deposits.
- Databases on identified resources are available and accessible via the MICA platform. However, there are gaps on identified resources for specific countries and/or commodities.
- Not all databases on identified resources are in the public domain. These databases are not accessible via the MICA platform.
- There are no databases available for undiscovered resources.
- Moving forward into a circular economy, the term endowment should include all resources, both geological and anthropogenic. This has not been attempted so far, but it is possible that the use of geological methods, models and knowledge can assist in the development of relevant methods to assess anthropogenic stocks.

Step 7: Schematic representation of the flowSheet

Figure 1 comprises a flowSheet diagram – a schematic representation of how the data and methods discussed above can be combined to answer the specified sub-questions.

The flowSheet diagram (Figure 1) illustrates the sequence of steps that are followed in answering the research question. For sub-question (a), concerning the size of the known or discovered copper resources in Europe, resource data, harmonised where possible, are aggregated from diverse sources such as reports on past exploration, maps and databases. For sub-question (b), concerning the size of the undiscovered resources, the small amount of available data is extracted from published sources. In addition, this may be supplemented by estimates of undiscovered resources based on a range of geological studies, including geophysical, geochemical, mapping and sub-surface investigations, such as trenching and drilling. Using established models for the various types of copper deposits, specialist experts are then able to derive a quantitative estimate of the undiscovered copper resources. It is important to note that this reflects only the geological stocks of copper in Europe.

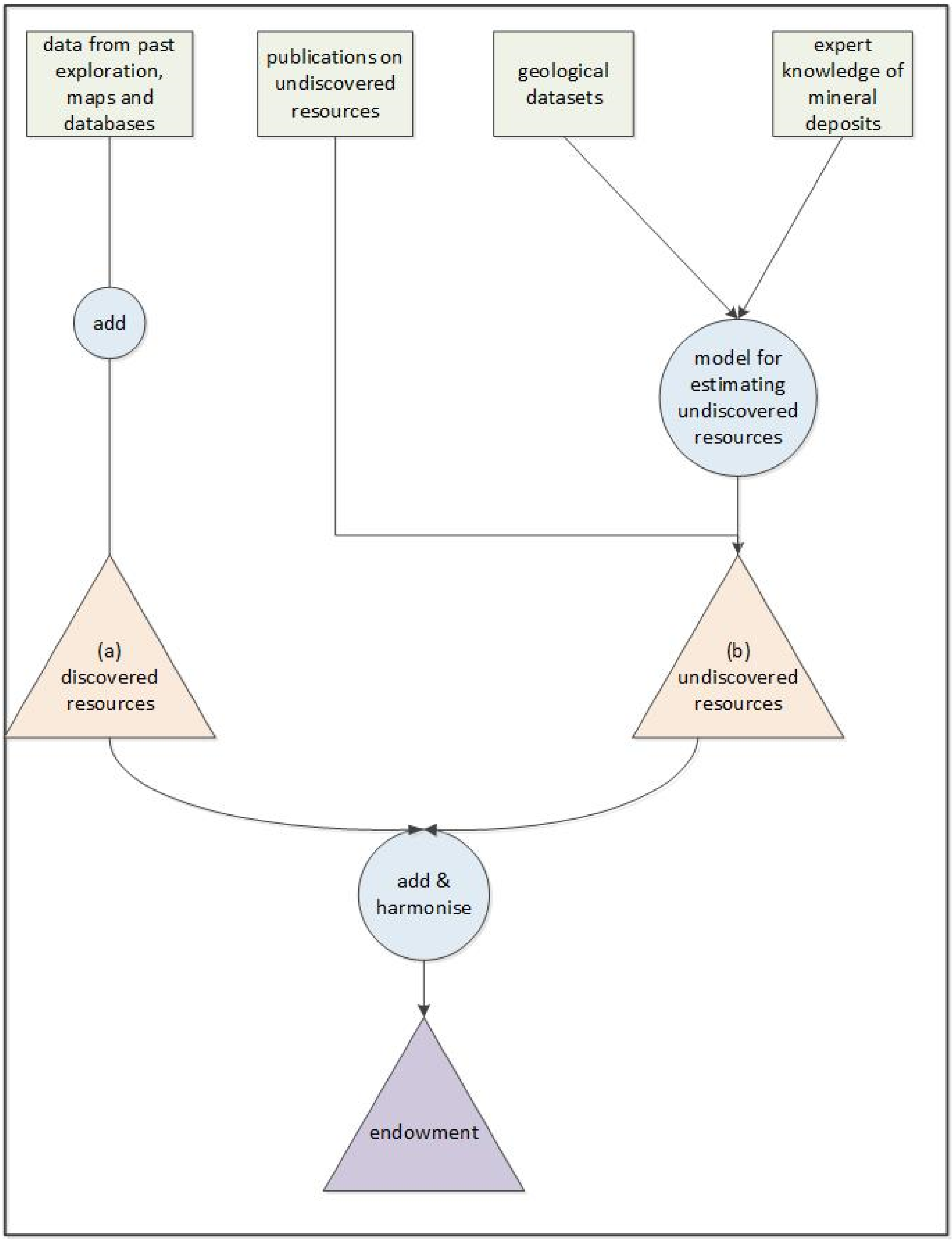

Figure 1 FlowSheet diagram of research question 1: What is the total mineral endowment of copper in Europe? (a) and (b) refer to the two sub-questions mentioned in the text.

3.2 Question 2: What is the recycling and recovery level of IT and technology equipment?

Step 1: Identify the type of question

This is a 'what' question seeking to quantify the level of recycling and recovery of IT and technology equipment.

Step 2: Classify the question

Scope	Keywords	Comments
COMMODITIES:	Discarded equipment (except discarded vehicles, batteries and accumulators)	WEEE
PROCESS_ CHAIN(activity):	ReUse_Recycling	ReUse, Recycling, Recovery
IMPACTS:	n.a.	
SPATIAL(activity):	unspecified	
SPATIAL(impact):	n.a.	
TEMPORAL(activity):	Present	
TEMPORAL(impact):	n.a.	
FLOWS:	Waste	
STOCKS:	n.a.	

Step 3: (I) Specify question

The original question is defined in general terms and should be translated into something more precise. The first step is to specify the *geographical boundary* and which end-of-life *products/waste streams* should be considered. In addition certain other aspects need to be specified more closely in order to provide an appropriate answer. The question should include the following points:

- What is the geographical boundary?
- Which commodity? Or which mineral/metal?
- Which products/waste streams specifically?
- Does the question refer to absolute amounts (tonnes) or relative amounts (a percentage, like recycling rate or recovery rate)?
- How is the recycling level defined?
    1) Is the stakeholder interested in a broader view, including not just material recycling but also product reuse, refurbishing, remanufacturing? We are assuming this not to be the case.
    2) How do we define material recycling?
        - EoL Recycling Rate
        - Recycled Content, including industrial waste
        - Recycled Content, excluding industrial waste

So the question, for example, might be rephrased as:

What is the material recycling level of Waste Electrical and Electronic Equipment (WEEE) in the EU28, in terms of absolute streams (quantity)?

Or

What is the EoL recycling rate of materials from WEEE (relative)?

Step 3: (II) Define relevant sub-questions

To answer the research question the following sub-questions need to be answered:

a) How much WEEE is collected in the EU28?
b) What is the fate of WEEE in the EU28, and, more specifically, how much of it is entering a material recovery process?
c) What is the composition of WEEE, in terms of component content of products and mineral/metal content of components?

Step 4: Define data needs and identify data gaps

To answer the question several datasets are needed. For example:

- Waste Electrical and Electronic Equipment (WEEE) inventories with information on their
    1) type and
    2) amount

  In case waste statistics are lacking, the generation of waste can be estimated using dynamic Material Flow Analysis. In this case consumption data on electrical and electronic equipment are a requirement (see step 5). Consumption data of products can either be given or derived from production and trade statistics (see Europroms database).
- Fate of WEEE
    1) landfilled/incinerated
    2) exported
    3) put back in use as a product: reused, refurbished, remanufactured,
    4) entering a recycling facility for material recovery
- Material composition of WEEE
- Efficiency of recycling process with regard to material recovery fraction (recovery rate)

Relevant information might be found in the following databases accessible through the MICA platform:

- ProSUM[6] for the EU28. The project aims to provide an inventory of urban mines, particularly of critical raw materials, as present in WEEE, ELVs, waste batteries and mining wastes. This information can be used for answering sub-question c.

[6] www.prosumproject.eu/

- Eurostat waste statistics should provide the answer to sub-questions (a) and (b), also for EU 28.
- Europroms (combined production and trade statistics to enable the calculation of final consumption data on products) from Eurostat.

However, there are some data gaps. Both databases only represent the European situation and data on a global level is lacking. Data for individual countries are lacking, and there is no harmonised method of reporting. Also the waste statistics from Eurostat are of low quality, often incomplete, lacking detail and not harmonised.

Step 5: Define methods needs and identify methods gaps

In case waste statistics are lacking the generation of waste can be estimated. The most relevant method to tackle this kind of question related to flows and stocks in an economy is Material Flow Analysis (MFA). In particular a dynamic MFA, including final consumption of electrical and electronic equipment, life span of products and material content, can be useful here. The method is not standardised but some conventions are observed in the field. Brunner & Rechberger (2004) have developed a practical handbook of MFA, linked to the MFA software tool 'STAN'. This handbook is limited to static MFA, but issues of terminology and system boundaries are similar for the dynamic MFA (dMFA) variant. Dynamic MFA can be used to translate the available flow-related information of certain materials into stock-related information, which in turn can be translated again into waste flows. This approach is valuable when statistics are lacking, or for exploration of future waste flows. Missing data are estimated using data on trade, production and consumption combined with an often-estimated life span. A dynamic MFA (dMFA) case study is presented in the MICA Deliverable D4.3 report (Hamilton et al., 2017).

Step 6: Expert knowledge and conclusions

- There is a need for clear globally harmonised definitions related to the end-of-life treatment of commodities, e.g. recycling, recovery, recycling rate, recycled content.
- The term "commodity" is not used in the same way by different disciplines. Among geologists it may simply indicate an ore, a mineral or a metal. In economics, and in wider society, it refers to any physical entity that is traded and, therefore, includes products and even waste streams.
- At the European level databases are available on the type, amount and fate of WEEE. However, these databases are immature and there are major data gaps in the European waste statistics. The data should, therefore, be used with caution.
- At the global level databases on the type, amount and fate of waste are lacking. There is a need for a globally harmonised method to monitor the type, amount and fate of waste (not only WEEE). There is also the need for the provision of harmonised data at global level, similar to trade statistics. At the moment such data are dispersed.
- Some databases on the metal/mineral content of components and products have been compiled, for example by the EU ProSUM project. However, these databases are not comprehensive or standardised.

- Dynamic Material Flow Analysis can help in estimating waste flows in the absence of waste statistics, by using production, trade and consumption data to estimate waste. However, for these estimates to be reliable the aforementioned data should be harmonised, comprehensive and of good quality. Harmonisation across different datasets, especially between production and trade, at the moment is not adequate and several assumptions need to be made when using them to estimate waste generation.

Step 7: Schematic representation of the flowSheet

Figure 2 represents a schematic representation of the steps to be followed to answer the sub-questions identified in Step 3.

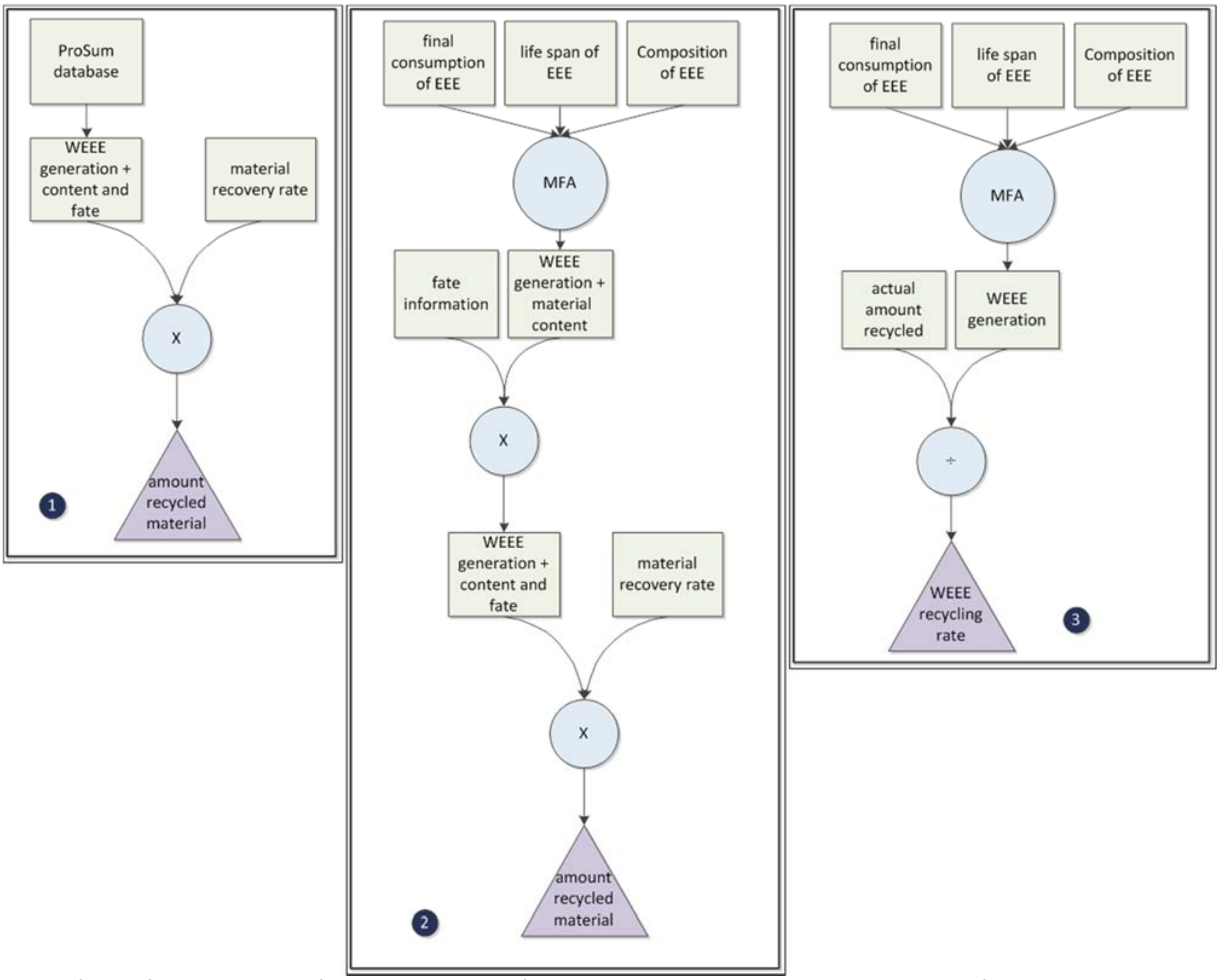

Figure 2 FlowSheet diagram of research question 2: What is the recycling and recovery level of WEEE in the EU28, in terms of absolute streams (1, 2)? Or What is the recycling and recovery level of WEEE in the EU28, in terms of relative EoL RR (3)?

3.3 Question 3: How does trade influence security of supply?

Step 1: Identify the type of question

This is a 'how' question asking for an explanation and evidence for how the trade in commodities may influence security of supply.

Step 2: Classify the question

Scope	Keyword	Comments
COMMODITIES:	unspecified	ALL, or should be specified
PROCESS_ CHAIN(activity):	ALL	
IMPACTS:	economic	
SPATIAL(activity):	unspecified	Demand company, national or regional level; Supply Global
SPATIAL(impact):	unspecified	company, national or regional level (e.g. Europe)
TEMPORAL(activity):		Government focus is Future Long Term, Future Very Long Term; Companies will be focussed on Future Short Term
TEMPORAL(impact):		Government focus is Future Long Term, Future Very Long Term; Companies will be focussed on Future Short Term
FLOWS:		Import, Export, Production, Waste
STOCKS:	ALL	

Step 3: (I) Specify the question

The type of stakeholder asking this question will greatly influence the answer provided. Most SMEs will generally be interested in short-term risks for their own supply chain. Most big companies assess risks to supply associated with their procurement activities and this information will not be in the public domain. However, many SMEs lack the capacity to estimate such risks and accordingly they are more likely to consult the MICA platform with such a question, although it is likely to relate to specific commodities and trade flows and the timeframe is likely to be short (i.e. assess short term risks). Governments are likely to be interested in broader supply risks in the longer term for the total economy. In this flowSheet we have focussed on the latter.

It will generally be necessary to specify the particular commodities of interest because each is different and no single generic answer is likely to be satisfactory. For a particular metal or mineral it will also be important to define whether we refer to raw materials, intermediate products or final products, or all of these. However, a government may also be interested in the supply of the total package of commodities, i.e. the total amount of mineral and metal in all forms.

So the question, for example, could be rephrased as:

How does trade influence the security of supply of commodities (e.g. copper) to meet the demand in the EU28 in the long term and very long term?

Step 3: (II) Define relevant sub-questions

a) What are the imports, exports and domestic production within the EU for the specified commodities?
b) Which countries and companies are the major suppliers to the EU?
c) How reliable are supplies to the EU from each supplying country?
d) Are there countries dominating the production of the specified commodities7 ?
e) Are there any trade agreements and/or trade restrictions specified between the major trading suppliers and the EU?
f) Are there countries outside the EU competing or monopolising the trade of the specified commodities?

Step 4: Define data needs and identify data gaps

In order to answer the sub-questions the following datasets are needed:

- Trade and production statistics (used in sub-questions a, b, f):
  1) production statistics
  2) trade statistics (including country of origin)
- Governance and Country concentration (used in sub-questions c and d):
  3) world governance indicators
  4) country concentration[8]
- Trade agreements and restrictions (used in sub-question e)
  5) country-specific trade restrictions (current and recent)
  6) trade agreements between the EU and other countries

Relevant information is available in the following databases:

- PRODCOM[9] (production statistics of EU) from EUROSTAT
- COMEXT[10] (trade statistics of EU) from EUROSTAT
- Europroms[11] (combined production and trade statistics to enable the calculation of apparent consumption) from EUROSTAT
- Production statistics of minerals and metals from USGS[12]/BGS[13]
- World governance indicators (WGI) database[14] of the World Bank

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[7] For an indication of reliability the World Governance Indicators (WGI) produced by the World Bank are commonly used.
[8] HHI index: www.investopedia.com/terms/h/hhi.asp
[9] http://ec.europa.eu/eurostat/web/prodcom
[10] http://ec.europa.eu/eurostat/web/international-trade-in-goods/data/focus-on-comext
[11] http://ec.europa.eu/eurostat/web/prodcom/overview/europroms
[12] https://minerals.usgs.gov/minerals/pubs/commodity/
[13] www.bgs.ac.uk/products/minerals/statistics.html
[14] http://info.worldbank.org/governance/wgi/#home

- Country-specific trade restrictions for the EU are available from the OECD[15]
- Trade agreements between the EU and other countries[16]
- Criticality assessments such as recently updated for the EU (EC, 2017)

The aforementioned databases, together with several additional information sheets (e.g. docSheets, factSheets) that provide information on trade agreements, criticality assessment methods and others, are available through the MICA platform.

The Eurostat trade statistics are considered comprehensive, but depending on the commodity of interest, data may not be available (e.g. for the minor metals). The production statistics seem to be less comprehensive and of lower quality. Production statistics for several raw materials, intermediate and final products are lacking, while for some materials data are aggregated and it is therefore difficult to differentiate individual commodities. Also, due to confidentiality rules, data for certain commodities and countries are not available. Europroms is being developed to link production statistics to trade statistics so that apparent consumption can be calculated. However, the development of the database is still in progress. It is not clear how reliable the linkages between trade and production categories are and thus how reliable the derived apparent consumption statistics are.

The OECD exports restriction database provides information on export restrictions from OECD countries between 2009-2014 at the six-level of the HS2007 classification. An update to the inventory to include data beyond 2014 has not taken place and the restrictions listed are for selected countries only.

Identifying the status of trade agreements between the EU and other countries is not straightforward. It requires the interrogation of the trade agreement documents as different rules apply for different countries.

Step 5: Define methods needs and identify methods gaps

Assessing the criticality of the present situation is easier than assessing it for the future because data are available to support the analysis. Assessing criticality risks for the future requires the prediction of future supply and demand market dynamics. Without an analysis of future demand and supply, any answer to the question is bound to be speculative and might include observations such as "trade improves the availability of resources for all" or "the risk of having a global market is that countries or regions do not have to develop their own supply".

In the past decade a range of criticality methodologies have been developed for assessing supply risk, but their results are normally restricted to the short term (10 to 15 years). The most relevant method to tackle questions related to future trade, consumption and production patterns is Dynamic Material Flow Analysis and modelling (MFA) combined with scenar-

[15] www.oecd.org/tad/benefitlib/export-restrictions-raw-materials.htm
[16] http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/

io analysis. Demand projections can be made using trend information from past time series and information on identified drivers for demand. To answer the question the origin of the supply (import, production) should be known, not just for the present but also for the future. This relies on assumptions about the development of mine production, and could be explored by scenario analysis, as it is impossible to forecast. In that way, what-if assumptions can be tested on their consequences for trade-dependency of supply.

Step 6: Expert knowledge and conclusions

- Even though the question posed by the stakeholder seems relatively simple, in reality it is difficult to answer. In this instance, it is very important to understand who is asking the question. Is it a company, a national government or the EC? The main implication will be on the data to be used during the assessment, but also the life cycle stage(s) to be considered in the analysis. For example, a company will most probably be interested in a specific life cycle stage. If it is a national government, then national statistics should be used in the analysis instead of the Eurostat database. In our analysis we assumed that the question relates to the EU.
- It is also very important to specify the commodities to be considered in this analysis. Supply and demand patterns are not the same for all commodities. The data requirements as well as data gaps will depend on the commodity being investigated.
- On a European level databases are available on domestic production (PRODCOM), import and export (COMEXT) of commodities, but they have limitations and are misaligned. For example, there is not necessarily one-to-one alignment between the classification systems used by COMEXT and PRODCOM, even though mapping documents exist. Confidentiality rules restrict the publication of some data and production statistics for raw materials, intermediate and final products are often not detailed enough for the analysis.
- There is a dedicated database, Europroms, which links trade and production statistics to facilitate the estimation of apparent consumption of commodities. However, the development of the database is still in progress. It is not clear how reliable the linkages between trade and production categories are.
- There are well established indicators to assess the reliability of supply for a given country, like World Governance Indicators (WGI).
- The trade restriction databases of the OECD is useful, but periodical updates are required. Expansion of the scope of the database to include more countries and commodities is also needed.
- In order to understand how trade influences the security of supply of commodities, we have to estimate future supply and demand and to investigate the role of trade in these dynamics. Dynamic Material Flow Analysis in combination with Scenario Analysis are useful tools for analysing the above. However, it is important that the boundary conditions of such an analysis, as well as the system and any assumptions made are clearly defined and aligned well with identified drivers.

- Further information about developing scenarios analysis and identifying available foresight methods can be accessed by the publicly available MICA Work Package 5 deliverable reports D5.2 and D5.5 (Hamadova et al., 2017; Martins and Bodo, 2017)

Step 7: Schematic representation of the flowSheet

The flowSheet in Figure 3 presents the sequence of steps that are followed in answering the research question. There are two sequential steps to be followed to enable a long-term future prediction to be undertaken, with multiple sub-steps.

<u>Step 1: Assess supply and demand patterns for the specified commodity at present.</u>

- Production and trade data including a system with well-defined boundaries needs to be constructed to enable the development of a material flow analysis (MFA) model.
- The constructed MFA model provides detailed information about the supply of materials across the different life cycle stages specified by the system.
- Supply information from the MFA model are used to calculate the import reliance indicator (import reliance = net imports / apparent consumption).
- The import reliance indicator is adjusted in terms of the governance index (WGI) and country concentration (HHI), as well as in terms of any trade restrictions and trade agreements. All these parameters are additional factors that may mitigate or increase the likelihood of supply disruption and they have to be accounted for.
- The outcome of this process is the identification of problematic trade flows that may influence the security of supply.

<u>Step 2: Assess the future impacts of trade on security of supply</u>

- Depending on the scope of the study, different potential futures may be explored through scenario analysis. Future scenarios should have a clear goal of ‘where are we aiming to get to?’ and should be described in sufficient detail by quantitative metrics and well-informed assumptions.
- The goal and details of the future scenario will determine the datasets and metrics required to calculate future commodity demand. The selection of datasets to calculate future demand is case specific and depends on the questions we are trying to answer. For instance, if the future scenario relates to climate change, then parameters, such as the Paris agreement targets, population growth and GDP may represent the preliminary data to describe it.
- The calculated future demand is assumed to be met by future supply. Future supply comprises production and trade flows which are adjusted accordingly to generate a future-informed MFA model following the steps described in Step 1.

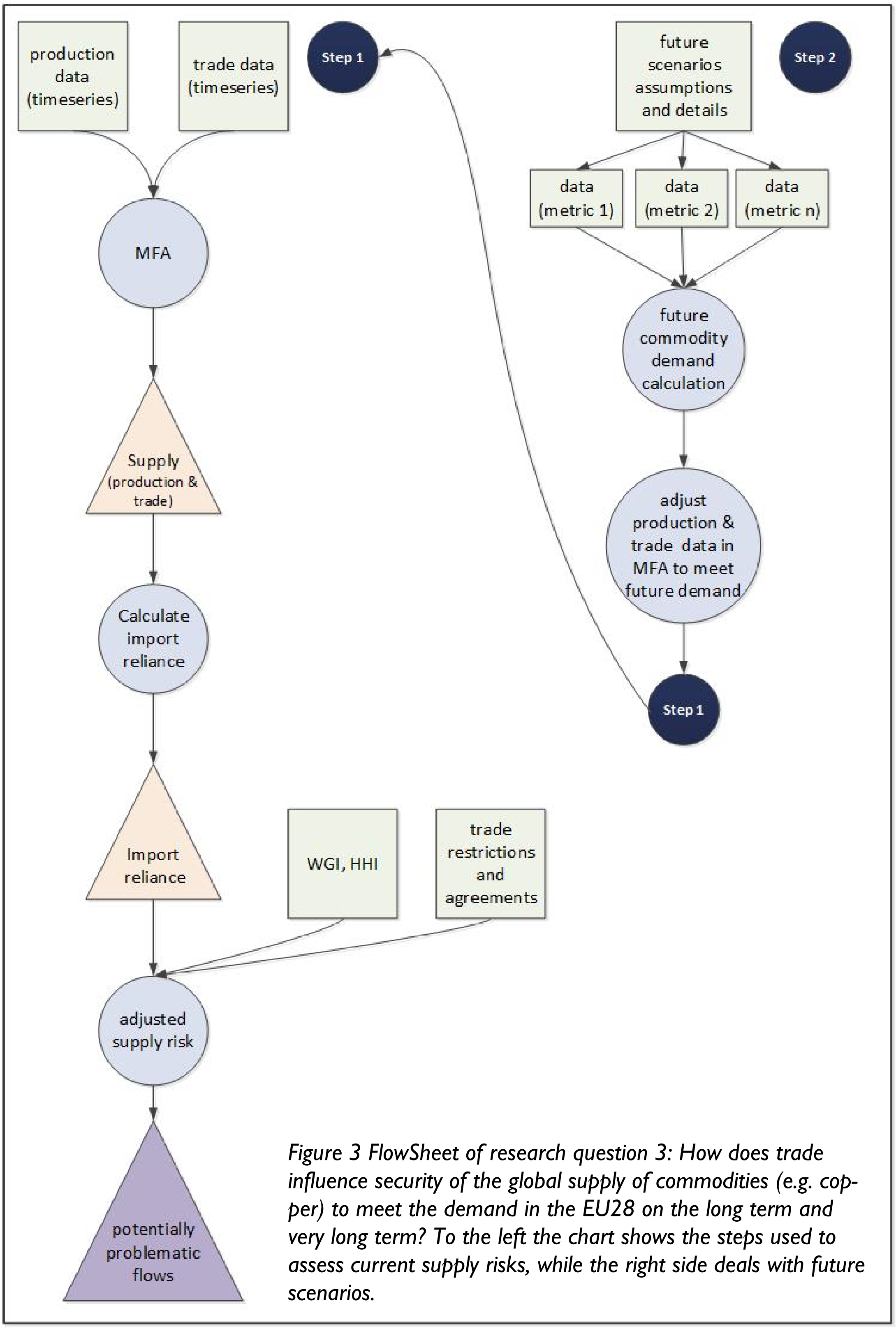

Figure 3 FlowSheet of research question 3: How does trade influence security of the global supply of commodities (e.g. copper) to meet the demand in the EU28 on the long term and very long term? To the left the chart shows the steps used to assess current supply risks, while the right side deals with future scenarios.

3.4 Question 4: How may designated areas (e.g. national parks) restrict exploration/extraction of commodity x in region/country y?

Step 1: Identify the type of question

This is a 'how' question asking how designated areas may restrict exploration and extraction activities for a specific commodity and location.

Step 2: Classify the question

Scope	Keyword	Comments
COMMODITIES:	ALL	Should be specified
PROCESS_ CHAIN(activity):		Exploration, Mining
IMPACTS:	ALL	
SPATIAL(activity):		Local Level, Site Level
SPATIAL(impact):		Local Level, Site Level
TEMPORAL(activity):		Present, Future Short Term, Future Long Term
TEMPORAL(impact):		Present, Future Short Term, Future Long Term
FLOWS:	Production	
STOCKS:	n.a.	

Step 3: (I) Specify the question

The question is initially defined in very general terms. The question should be formulated more closely to specify the commodity (e.g. copper) and country (e.g. Germany) to which the question refers.

So the question, for example, could be rephrased as:

How may designated areas restrict exploration/extraction of *copper* in *Germany*?

Step 3: (II) Define relevant sub-questions

a) In which region/country are the exploration and mining targets located?
b) Which area/location are the targets for exploration and/or extraction?
c) What type of designation(s) coincide with the areas to be licensed for exploration and/or extraction?
d) What kind of exploration and mining activities are proposed and for what commodity?

There are many different types of designated areas, some of which are unique to individual countries and others applied more widely across the EU. These include:

- national parks
- areas of outstanding natural beauty
- sites of special scientific interest

- heritage classifications
- sites of special archaeological interest
- Natura 2000

Each designation is associated with a set of restrictions that specify what activities may be permitted and under what conditions. These restrictions may vary between countries for a particular type of designation. Furthermore, within an individual country different regions may impose different restrictions or different sets of operating conditions on a specific activity proposed for a particular class of designated area.

The restrictions imposed within a designated area will also depend on the type of operation, either exploration or mining, and the type of mining, for which a license is sought. In general exploration activities are surface investigations of short duration with relatively minor disturbance. However, they vary widely from surface sampling of rocks and soils which may last only a few days in a given prospect to pitting, trenching and drilling activities that may involve large machines operating for periods of several months. In contrast, mining involves long term production activities operating on a much larger scale, generally for periods exceeding 10 years. However, depending on the commodity that is mined and the nature of the deposit in which it is located, there can be significant variation in the surface footprint of the mining operations and ancillary infrastructure.

Step 4: Define data needs and identify data gaps

In order to answer the sub-questions the following datasets are needed:

- GIS of designated areas by country
- Country-specific legal restrictions for a specific designation

In general all EU countries will have a map, generally in digital form, showing the location and type of designations within its national boundaries. Relevant information about restrictions can be found in the EURlex database, which contains legal documents on permitting and licensing at EU level. If this does not contain sufficient information, it may be necessary to examine closely the legislative rules around designated areas of the country in question.

The EURlex databases are accessible through the MICA platform. The MICA platform does not give access to country-specific GIS data on designated areas.

Step 5: Define methods needs and identify methods gaps

The decision whether or not to allow exploration or mining activity in an area will depend on the restrictions imposed by each country and the type of designation area.

Step 6: Expert knowledge and conclusions

- This is a relatively simple question to answer providing the target areas for possible exploration and mining are clearly identified.

- Information about permitted and restricted activities within designated areas in EU member states is well defined and readily accessible, although there may be significant variation between and within countries on certain aspects and their detailed enforcement. Specific local conditions, for example related to environmental, social and infrastructure issues, may also influence whether an activity is restricted, regardless of what is legally permissible within a particular type of designation.

Step 7: Draw up a flowsheet

Figure 4 shows the flowSheet to answer the specified sub-questions.

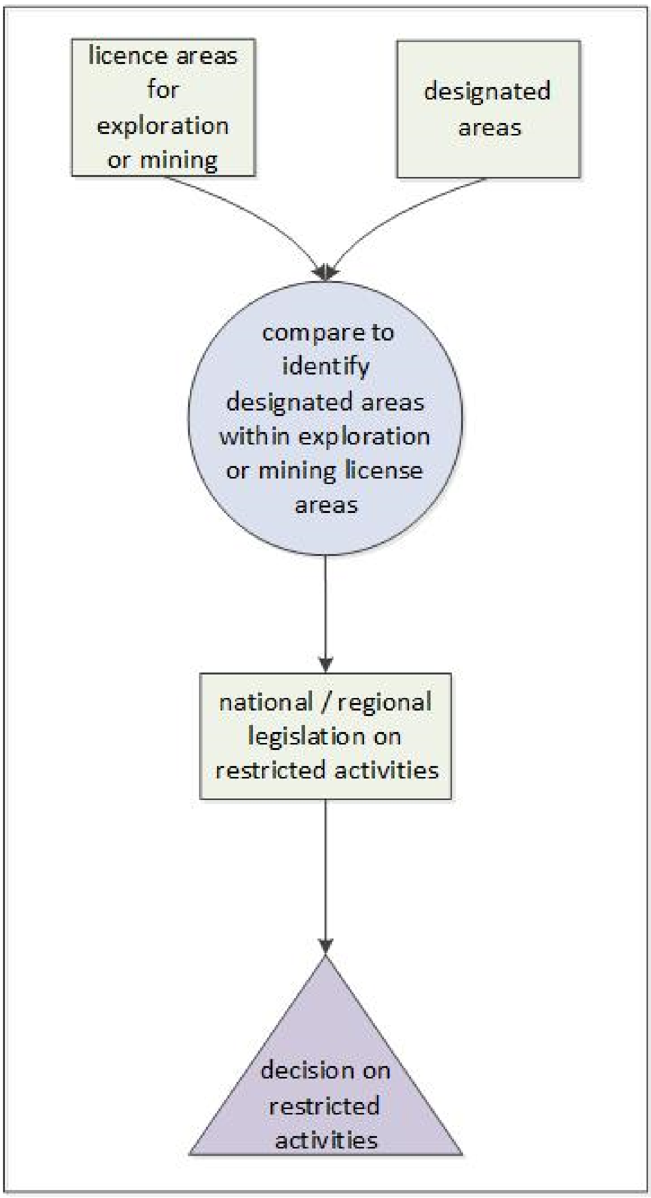

Figure 4 FlowSheet of research question 4: How may designated areas restrict exploration/extraction of copper in Germany?

The flowSheet (Figure 4) illustrates the sequence of steps that are followed in answering the research question. The first two stages entail identifying what, if any, designated areas lie within or coincide with part of the area that is licensed, or for which a licence application is being considered, either for mineral exploration or mining. Once this is ascertained the legislation relevant to restricted and permitted activities within a designated area of a particular type will determine the answer to the question. It is then a relatively simple matter of determining whether the proposed exploration and/or mining activities are restricted by law within the country or region of interest.

3.5 Question 5: What are the environmental impacts of recycling versus mining for commodity x?

Step 1: Identify the type of question

This is a 'what' question aiming to identify and compare the environmental impacts associated with recycling and mining of a specific commodity.

Step 2: Classify the question

Scope	Keyword	Comments
COMMODITIES:	all	It needs to be specified
PROCESS_ CHAIN(activity):	all	
IMPACTS:	environmental	
SPATIAL(activity):	global level	
SPATIAL(impact):	global level	
TEMPORAL(activity):		Present, Future Short Term
TEMPORAL(impact):		Present, Future Short Term, Future Long Term, Future Very Long Term
FLOWS:		Production, Consumption, Waste, Emission
STOCKS:	n.a.	

Step 3: (I) Specify the question

In order to be able to more closely specify the question, the following need to be taken into consideration:

- What type of environmental impact assessment is required (local environmental Risk Assessment, generic Life Cycle Assessment)?
- What is the commodity of interest (e.g. copper)?
- Which product or product category should be considered (e.g. WEEE - Waste Electrical and Electronic Equipment)?
- What types of mining operations and of what scale should be taken into account in the calculation, (open pit, underground, large or small scale)?

Answering these questions is essential to the process of developing an appropriate response for the stakeholder. These answers will influence the data and method(s) to be used. For instance, if the interest is in identifying environmental impacts at the local scale, then Environmental Risk Assessment is more suitable. However, if the focus is on whole life environmental impacts then Life Cycle Impact Assessment (LCA) is a more appropriate method.

The question therefore could be rephrased:

What are the local specific environmental impacts of producing copper from WEEE versus mining copper at a given location?

or

What are the generic cradle to grave environmental impacts of producing copper from WEEE versus mining copper?

Step 3: (II) Define relevant sub-questions

Local scale – Environmental Risk Assessment:

a) What are the local specific environmental impacts of producing copper from WEEE at a given location?
b) What are the local specific environmental impacts of mining copper at a given location?

or

Life Cycle Impact Assessment:

c) What are the generic cradle to gate environmental impacts of producing copper from WEEE?
d) What are the generic cradle to gate environmental impacts of producing copper from mines?

Step 4: Define data needs and identify data gaps

Environmental Risk Assessment:

In order to answer the sub-questions a) and b) using Environmental Risk Assessment the following datasets are needed:

physical/chemical databases of hazardous substances

- toxicological databases on hazardous substances
- GIS data about population density in the neighbourhood of an installation
- local information on activity and volume and installations needed for the mining operation
- local environmental conditions, baseline geological/environmental situation (before and after)

Relevant information for ERA data can be found in databases maintained in the context of REACH[17]. REACH-related databases are available through the MICA platform.

[17] www.reach.lu/en and http://echa.europa.eu/information-on-chemicals

All local specific data on the installation, environmental conditions and population density should be gathered on a case-specific basis.

Life Cycle Assessment:
In order to answer the sub-questions c) and d) using Life Cycle Assessment the following datasets are needed:

- Life Cycle Inventory data (LCI) (emissions and extractions of processes in a defined process chain)
- Life Cycle Impact Assessment data (LCIA)

Relevant information about LCI data can be found in databases: Ecoinvent[18], ELCD[19], Gabi[20] UNEP SETAC Life Cycle Inventory database[21], etc. Relevant information about LCIA data can be found in databases: CML2002[22], ILCD[23], ReCiPe[24] etc. Several LCI and LCIA databases are accessible through the MICA platform.

In LCA case studies data on foreground processes, i.e. producing copper from WEEE and mining of copper, should be gathered on a case-specific basis. However, supplementary data for background processes might also be available in existing databases, like Ecoinvent, ELCD, Gabi etc. However, data for recycling and mining processes might need improvement in these background LCI databases.

Step 5: Define methods needs and identify methods gaps

Life Cycle Assessment is a method to assess the environmental impacts relevant to a "functional unit", which can represent a product or a service. In this case, the functional unit would be, for example, 1 kg of copper produced via either recycling or mining. LCA ideally uses a cradle-to-grave perspective, i.e. includes all processes related to the function unit, production, transport, use, and waste management. In the case of a material, the LCA system boundary is often cradle-to-gate, since the "grave" is often unknown and not always relevant for the stakeholder question. This appears to be the case here as well.

The method of LCA is standardised by the International Organization for Standardization in ISO 14040/14044 (ISO, 1996 and ISO, 2006). There are also European initiatives to harmonise the performance of LCA in compliance with ISO, like the International Reference Life Cycle Data System (ILCD) (EC, 2010a EC, 2010b) and Product Environmental Footprint (PEF)/Organisation Environmental Footprint (OEF) (EC, 2016).

18 www.ecoinvent.org/
19 http://eplca.jrc.ec.europa.eu/ELCD3/processList.xhtml?stock=default
20 www.gabi-software.com/international/databases/gabi-databases/
21 www.lifecycleinitiative.org/
22 www.universiteitleiden.nl/en/research/research-output/science/cml-ia-characterisation-factors
23 http://eplca.jrc.ec.europa.eu/?page_id=1159
24 www.rivm.nl/en/Topics/L/Life_Cycle_Assessment_LCA/ReCiPe

Environmental Risk Assessment Guidelines have been developed by the OECD, the EU and US EPA. The ERA method aims at specifying ecosystem health risks of plants or factories at the local level. Emissions from the plant are followed, or rather modelled, to their fate in the environment, leading to environmental concentrations that can be compared with no-effect levels.

A number of academic societies, such as SETAC, ECETOC, SRA, are dealing with Health Risk Assessment (HRA) and/or Environmental Risk Assessment (ERA). Until now ERA has not been formally standardised by ISO. In the REACH program of the EU, a high level of standardisation has been obtained. There are many different models (distribution models, intake and toxicity models) available for Risk Assessment and Environmental Risk Assessment.

Step 6: Expert knowledge and conclusions

- The type of environmental impacts the stakeholder is interested in will determine the method and data to be used, either Life Cycle Impact Assessment (LCA) or Environmental Risk Assessment (ERA).
- There are standard harmonised methods to perform LCA and ERA (EC, 2010; EC, 2016; Guinée *et al.,* 2002; ISO, 1996; ISO, 2006). Both methods allow for methodological choices that have an impact on the outcomes.
- Relevant information for ERA data can be found in databases maintained in the context of REACH.
- There are several dedicated databases for Life Cycle Inventory data (LCI) and Life Cycle Impact Assessment data.
- Some LCI data are available in the public domain, but most are in commercial databases. LCIA data are generally available in the public domain.
- Technical input and engagement with the industries for which an assessment of environmental impacts is required is essential in order to collect fit-for-purpose data. For instance, in ERA case-specific data on the site characteristics and local environmental information are important. Equally, for developing accurate LCA models primary data provided by the industry are often required to quantify the environmental impacts of foreground processes, or otherwise technical input to adjust background processes deriving from existing databases.

Step 7: Draw up a flowSheet diagram

The flowSheet in Figure 5 illustrates the sequence of steps that are followed to answer question 5. As discussed earlier, there are two possible approaches depending on whether the question concerns generic cradle-to-grave environmental impacts (diagram 1 in Figure 5), or local specific environmental impacts (diagram 2 in Figure 5).

The assessment of the generic cradle-to-grave environmental impacts associated with the recycling of copper from WEEE and with mining for copper requires the use of life cycle assessment. Life cycle inventory data and life cycle impact assessment data are required to develop LCA models. Note, however, that data provided through engagement with technical experts are also essential to enhance such models and to adjust background processes described in standard databases.

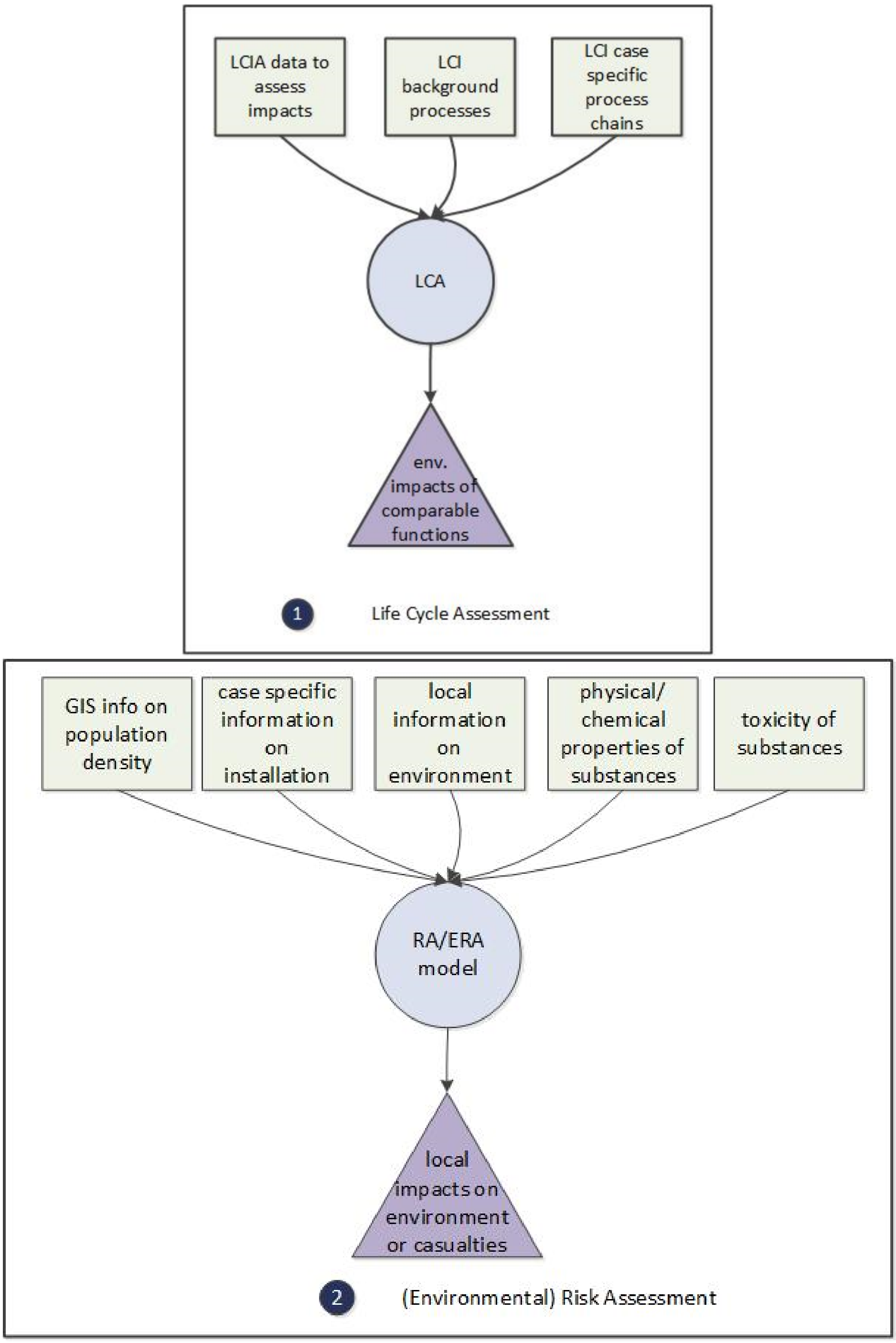

Figure 5 FlowSheet for research question 5: (1) What are the generic cradle to grave environmental impacts of recycling of WEEE versus mining for copper? or (2) What are the local specific environmental impacts of recycling of WEEE versus mining for copper at a given location?

The assessment of local specific environmental impacts can be done using environmental risk assessment. Several different datasets are required as input into ERA models, as specified in the diagram, many of them requiring site-specific information and, therefore, engagement with relevant expert communities.

4. General discussion and conclusions from applying the methodology to selected research questions

It is clear that answering stakeholder questions on raw materials is hardly ever a simple and straightforward affair. Nor is it sufficient to point out relevant databases and methodologies. To provide a multitude of stakeholders with widely different interests, backgrounds and levels of understanding with relevant information is indeed a task that requires the input of expertise as well as data and methods. As is also apparent from the exercise we went through, it is not just geological expertise that is required, but a much broader array of areas is relevant, such as economics, industrial ecology, environmental science, behavioural science, law and many more.

In this report, we developed a procedure that guides stakeholders, using a sequential approach, to develop relevant answers to their questions. The approach has been applied using five example questions provided by different stakeholder groups and they represent questions of a different nature. The procedure appeared to be applicable to a variety of questions and it consists of the following steps:

- Translate the stakeholder question, which is by nature imprecise, into a more refined and demarcated question or set of questions that can be answered using raw materials data and methods.
- Identify data needs and databases that could provide the relevant information.
- Identify the need for application of one or more specific methods, to process the data into relevant information.
- Provide expert insight about gaps in data or/and methods, issues with existing methodologies, datasets, technical input, uncertainties or other information that are hard to capture by reading a report or methodology manual.
- Outline a series of steps that stakeholders could follow to guide them to an answer.

Translating the stakeholder question into a researchable (set of) question(s)

In almost every case there will be a degree of uncertainty in the original research question concerning what the stakeholder is most interested in. This is best resolved by direct consultation with the stakeholder to ascertain the boundary conditions of the question. A first step is to clearly define the temporal and spatial boundaries of the enquiry, the commodities, raw materials and products of concern, together with any other relevant variables that determine the boundary conditions of the question, and therefore lead to the identification of data and methods. Generally, the translation involves devising a number of sub-questions intended to break down the overarching question into simple, or at least straightforward, steps. This, too, cannot be done without the stakeholders themselves.

A very important issue in this step is communication and vocabulary. Different disciplines use different terminology, so it is important to avoid confusion by explicitly clarifying concepts at the start. An example is the concept “commodity” which is taken by geologists to mean “ore” or “raw material”, but has a much broader significance for economists, indicating any tangible thing that can be traded, including semi-products, final products and waste. There is an overarching need for a comprehensive and widely accepted glossary of technical terms. This would allow experts and stakeholders alike to understand and use technical terminology and nomenclatures in a consistent and transparent manner.

Defining data needs

Once the question has been closely defined and translated into sub-questions, it is possible to identify the data that is required to answer it. In order to provide an appropriate and authoritative response the required data should be comprehensive, of high quality and harmonised throughout the area and time period to which the question relates. However, in many cases there are serious issues with data gaps and data quality which require estimates to be made and which may detract significantly from the reliability of the response that can be given. Further, datasets may not be sufficiently comprehensive or may lack the required level of granularity to answer the specified question. For example, the metal contents of many intermediate and final products are not specified and thus assumptions or generalisations have to be made, either on the basis of expert solicitation or from published studies that may not be directly relevant in terms of geographical scope or timescale. It is here that the direct input of experts is invaluable: in the absence of generally accepted data, experts can come up with an educated estimate that is much more appropriate.

In some cases the required data may not be available in the public domain and can only be accessed on payment of a fee. This may pose a serious barrier to the formulation of a robust answer to the research question. For example, questions concerning future supply, demand and depletion of minerals and metals, either globally or on a smaller scale, can only be answered with reliable harmonised data on mineral resources, reserves, production and consumption. Unfortunately, even within the EU reliable comprehensive data on mineral resources and reserves are available for only a few countries and, where they do exist, they are reported in a variety of systems that make standardisation and harmonisation difficult to achieve. Consequently it is generally very difficult to provide robust answers to questions concerning the future supply of minerals and metals.

Defining methods

For certain types of questions established methods exist that are both harmonised and standardised e.g. LCA and ERA. These methods are highly specific and answer questions in their own, standardised way. The advantage of such methods is that they are generally accepted and usually have their own datasets. However such methods may not be sufficiently flexible to provide satisfactory answers to all questions. For example, LCA generates information on environmental impacts at the micro-level of, for example, 1 kg of copper. The use of LCA for large scale issues should not be attempted without further guidance, to avoid invalid conclusions. Here, too, the expert advice is essential: how far can the LCA boundaries be stretched and in what way can we come to a relevant answer to a macro-scale question?

In other cases established methodologies may not be available and it may not, therefore, be possible to provide an authoritative reply to certain types of question. For example, questions concerning the mineral endowment of a particular area or country require knowledge of both the undiscovered and discovered resources present. While estimates of discovered resources may be available for some commodities in some countries, the estimation of undiscovered resources is a highly complex task that requires large amounts of diverse geological data, considerable technical expertise and in most cases additional research work to be undertaken.

A very important method that comes up frequently when trying to provide an answer to stakeholder questions, is Material Flow Analysis. This method, although well defined, is not standardised and therefore flexible. It is a useful method for application in a data poor environment. Based on mass balance, it can be used to estimate flows or stocks indirectly. The dynamic variant is applicable also for questions related to the future, for which data by definition do not exist.

Combining data and methods to provide answers to the questions

The MICA platform contains descriptions of databases and methods. In theory, stakeholders could figure out for themselves how to use these. In practice, this will hardly ever be the case unless stakeholders are experts in one of these areas themselves. This step, too, will be most effective if taken jointly between experts and stakeholders. For example, for some questions it may be sufficient to rely on the literature of published case studies, while others require a new study. The decision to undertake new research should not be taken lightly as considerable time and money may be involved. This decision is best made jointly, and if research is required, the expert may be able to identify relevant literature and additional global sources of expertise and data.

5. Concluding remarks

The two steps that are most sensitive and most difficult in the procedure outlined in Section 4, are the first and the last. The first step, translating the vague or imprecise stakeholder question into a researchable question, or set of questions, is essential to get the rest of the procedure right. That means the expert has to be very open minded and really focused on what the stakeholder actually wants to know. It also implies in many cases that not one, but several experts should be involved from different backgrounds. Most stakeholder questions are truly multidisciplinary in nature. The last step, combining data and methods to provide a sequential guide to reach an answer to the refined stakeholder question, proved to be the most demanding one in our workshop. The graphic flowSheets represent the different steps to take. It was very challenging to compile some of them. There were often several different possible interpretations for each one of the questions posed and, depending on how this question is interpreted, different flowsheets may have to be produced. Even after several attempts the flowSheets presented in this report may have not captured all the aspects of the topic that the stakeholder was interested in.

These two steps are essential, and in fact may be regarded as the essence of the MICA aim to transform information and expert knowledge into intelligence. The act of compiling flow-sheets represents that process. While putting together information on data and methods – a useful thing in itself – is relatively straightforward, this is not the case with expert advice. The implementation of flow sheets for a limited number of stakeholder questions may already be a challenge. For the time being, therefore, it remains necessary as well to generate answers to stakeholder questions in an open dialogue between stakeholders and experts.

The work presented in this report attempts to demonstrate the 'thinking' processes followed by experts when asked to answer research questions. As such, it communicates the uncertainties, complexities and difficulties the research community is faced with when prompted to provide authoritative and relevant responses to imprecisely formulated questions. A fundamental conclusion of this work is that it is essential that all stakeholders, both those asking the questions and those responding to them, have a clear understanding of the steps involved and of the associated tools that are available to respond to such questions. Raising awareness and understanding among all the parties involved, based on clear and transparent communication, is paramount.

6. Recommendations

Even though it is not possible to answer all stakeholder questions, developing pathways to potential answers, explaining the 'thinking process' and identifying related data and methods is very valuable. FlowSheets provide exactly this, they convey expert insight, raise awareness about the considerations that one should make (data and methods) and clearly outline the complexity of the research project. It is important that future research continues the work started here with the flowSheets and their full development is incorporated in a future edition of the MICA platform, using carefully designed functions based on the methodology explained in this report.

The provision of a good answer demands a clear and precise question. Breaking down an imprecise question posed and assigning boundary conditions can help to simplify it. The template and procedure described in this report may serve future research to enhance and possibly 'automate' the process. This should ideally be an integral part of the next edition of the MICA platform.

Combining data and methods to answer a question is not always straightforward, as it often requires expert insight by a multidisciplinary group of experts, including the stakeholder(s) who posed the question in the first place. Any future developments of flowSheets beyond the life of this project should ensure that multiple experts from different disciplines are involved in the process and that adequate interaction with the stakeholders who ask the questions is taking place.

One of the key conclusions of this work has been that 'intelligence is asking the right question' and 'knowledge is having the right answer'. Stakeholders, funding bodies, governments and others will reach intelligence when they are able to ask the right questions. To do so they require to be knowledgeable about the current research status quo and the availability of data, information, methods and experts. Once this knowledge is in place, then the right questions can be asked, which can 'push' research further to generate more data, further develop existing methods and develop new ones too.. The MICA project has been working towards building up background knowledge and identifying gaps, but also towards mineral intelligence with the flowSheet development. The recommendation about educating and empowering the general stakeholder community by promoting independent thinking is not often found in research reports. It is common practice for these reports and data platforms to provide answers. However, as has been repeatedly mentioned here, it is not possible to provide answers to all stakeholder questions, but it is possible to provide pathways to potential answers, if clearly defined questions are in place.

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8. Appendices

8.1 Keywords for classification of research questions

CommoditiesScheme
ALL
Metals
Critical raw materials
Energy commodities
Precious and semi-precious stones
Industrial Minerals
Sulphur and fertilizer minerals
Clays
Construction minerals other than clays
Mineral waste from construction and demolition
Other mineral wastes
Combustion wastes
Dredging spoil
Mineral wastes from waste treatment and stabilised wastes
Metallic waste, ferrous
Metallic waste, non-ferrous
Metallic waste, mixed ferrous and non-ferrous
Glass wastes
Discarded equipment (except discarded vehicles, batteries and accumulators)
Discarded vehicles
Batteries and accumulators wastes
chemicals and materials
intermediate products
final products
unspecified

ProcessChainScheme
ALL
Exploration
Mining
MaterialProduction
ProductAssembling
Use_Consumption
ReUse_Recycling
FinalDisposal
unspecified
n.a.

Impacts
ALL

environmental
social
economic
cultural
unspecified
n.a.

SpatialScheme
Global Level
Continental Level
National Level
Regional Level
Local Level
Site Level
Terrestrial vs. Marine
Corporate level
unspecified
n.a.

TemporalScheme
Geological
Historic
Recent Past
Present
Future Short Term
Future Long Term
Future Very Long Term
unspecified
n.a.
Flows
ALL
Import
Export
Production
Consumption
Waste
Emission
unspecified
n.a.

Stocks
ALL
Lithosphere
Anthroposphere

unspecified
n.a.

8.2 Workshop template and flowSheets for additional research questions

The completed templates and flowsheets of all 21 research questions as drafted during the flowSheet workshop in Leiden are reported in the supplementary excel spreadsheet, named ‘Appendix_FlowSheetTemplates.xlsx’.

Appendix_FlowShe
etTemplates.xlsx